Unit 10

SIMPLE HARMONIC MOTION AND WAVES

After studying this unit, students will be able to:

- state the conditions necessary for an object to oscillate with SHM.
- explain SHM with simple pendulum, ball and bowl examples.
- draw forces acting on a displaced pendulum.
- solve problems by using the formula $T = 2\pi\sqrt{\ell/g}$ for simple pendulum.
- understand that damping progressively reduces the amplitude of oscillation.
- describe wave motion as illustrated by vibrations in rope, slinky spring and by experiments with water waves.
- describe that waves are means of energy transfer without transfer of matter.
- distinguish between mechanical and electromagnetic waves.
- identify transverse and longitudinal waves in mechanical media, slinky and springs.
- define the terms speed (v), frequency (f), wavelength (λ), time period (T), amplitude, crest, trough, cycle, wavefront, compression and rarefaction.
- derive equation $v = f\lambda$.
- solve problems by applying the relation $f = 1/T$ and $v = f\lambda$.
- describe properties of waves such as reflection, refraction and diffraction with the help of ripple tank.

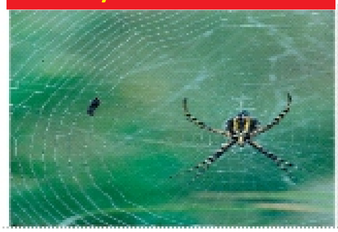
Science, Technology and Society Connections

The students will be able to:

- explain the diffraction of radiowaves but not of T.V waves (transmission can be heard in such areas where the waves cannot reach directly).

A body is said to be vibrating if it moves back and forth or to and fro about a point. Another term for vibration is oscillation. A special kind of vibratory or oscillatory motion is called the simple harmonic motion (SHM), which is the main focus of this chapter. We will discuss important characteristics of SHM and systems executing SHM. We will also introduce different types of waves and will demonstrate their properties with the help of ripple tank.

For your information



A spider detects its prey due to vibration produced in the web.

10.1 SIMPLE HARMONIC MOTION (SHM)

In the following sections we will discuss simple harmonic motion of different systems. The motion of mass attached to a spring on a horizontal frictionless surface, the motion of a ball placed in a bowl and the motion of a bob attached to a string are examples of SHM.

MOTION OF MASS ATTACHED TO A SPRING

One of the simplest types of oscillatory motion is that of horizontal mass-spring system (Fig.10.1). If the spring is stretched or compressed through a small displacement x from its mean position, it exerts a force F on the mass. According to Hooke's law this force is directly proportional to the change in length x of the spring i.e.,

$$F = -kx \quad \ldots\ldots\ldots \quad (10.1)$$

where x is the displacement of the mass from its mean position O, and k is a constant called the **spring constant** defined as

$$k = -\frac{F}{x}$$

The value of k is a measure of the stiffness of the spring. Stiff springs have large value of k and soft springs have small value of k.

As $\quad F = ma$

Therefore, $\quad k = -\frac{ma}{x}$

or $\quad a = -\frac{k}{m}x$

$$a \surd -x \quad \ldots\ldots\ldots \quad (10.2)$$

It means that the acceleration of a mass attached to a spring is directly proportional to its displacement from the mean position. Hence, the horizontal motion of a mass-spring system is an example of simple harmonic motion.

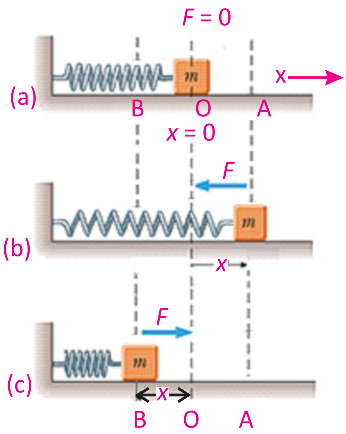
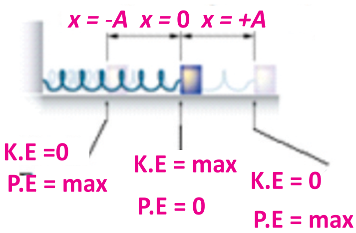


Fig.10.1: SHM of a mass-spring system

The negative sign in Eq. 10.1 means that the force exerted by the spring is always directed opposite to the displacement of the mass. Because the spring force always acts towards the mean position, it is sometimes called a restoring force.

A restoring force always pushes or pulls the object performing oscillatory motion towards the mean position.

For your information



Kinetic and potential energy at different positions in a mass–spring system.

Initially the mass m is at rest in mean position O and the resultant force on the mass is zero (Fig.10.1-a). Suppose the mass is pulled through a distance x up to extreme position A and then released (Fig.10.1-b). The restoring force exerted by the spring on the mass will pull it towards the mean position O. Due to the restoring force the mass moves back, towards the mean position O. The magnitude of the restoring force decreases with the distance from the mean position and becomes zero at O. However, the mass gains speed as it moves towards the mean position and its speed becomes maximum at O. Due to inertia the mass does not stop at the mean position O but continues its motion and reaches the extreme position B.

As the mass moves from the mean position O to the extreme position B, the restoring force acting on it towards the mean position steadily increases in strength. Hence the speed of the mass decreases as it moves towards the extreme position B. The mass finally comes briefly to rest at the extreme position B (Fig. 10.1-c). Ultimately the mass returns to the mean position due to the restoring force.

Tidbits

A human eardrum can oscillate back and forth up to 20,000 times in one second.

This process is repeated, and the mass continues to oscillate back and forth about the mean position O. Such motion of a mass attached to a spring on a horizontal frictionless surface is known as Simple Harmonic Motion (SHM).

The time period T of the simple harmonic motion of a mass 'm' attached to a spring is given by the following equation:

$$T = 2\pi\sqrt{\frac{m}{k}} \qquad \text{......... (10.3)}$$

Quick Quiz

What is the displacement of an object in SHM when the kinetic and potential energies are equal?

BALL AND BOWL SYSTEM

The motion of a ball placed in a bowl is another example of simple harmonic motion (Fig 10.2). When the ball is at the mean position O, that is, at the centre of the bowl, net force acting on the ball is zero. In this position, weight of the ball acts downward and is equal to the upward normal force of the surface of the bowl. Hence there is no motion. Now if we bring the ball to position A and then release it, the ball will start moving towards the mean position O due to the restoring force caused by its weight. At position O the ball gets maximum speed and due to inertia it moves towards the extreme position B. While going towards the position B, the speed of the ball decreases due to the restoring force which acts towards the mean position. At the position B, the ball stops for a while and then again moves towards the mean position O under the action of the restoring force. This to and fro motion of the ball continues about the mean position O till all its energy is lost due to friction. Thus the to and fro motion of the ball about a mean position placed in a bowl is an example of simple harmonic motion.

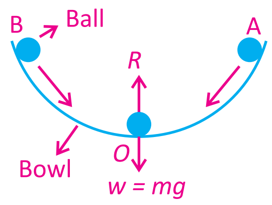


Fig. 10.2: When a ball is gently displaced from the centre of a bowl it starts oscillating about the centre due to force of gravity which acts as a restoring force

MOTION OF A SIMPLE PENDULUM

A simple pendulum also exhibits SHM. It consists of a small bob of mass '*m*' suspended from a light string of length 'ℓ' fixed at its upper end. In the equilibrium position O, the net force on the bob is zero and the bob is stationary. Now if we bring the bob to extreme position A, the net force is not zero (Fig.10.3). There is no force acting along the string as the tension in the string cancels the component of the weight $mg\cos\theta$. Hence there is no motion along this direction.

The component of the weight $mg\sin\theta$ is directed towards the mean position and acts as a restoring force. Due to this force the bob starts moving towards the mean position O. At O, the bob has got the maximum velocity and due to inertia, it does not stop at O rather it continues to move towards the extreme position B. During its motion towards point B, the velocity of the bob decreases due to restoring force. The velocity of the bob becomes zero as it reaches the point B.

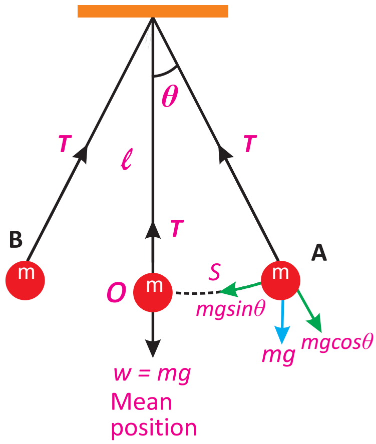
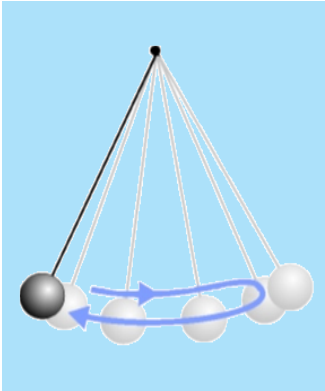


Fig. 10.3: Forces acting on a displaced pendulum. The restoring force that causes the pendulum to undergo simple harmonic motion is the component of gravitational force *mg* sinθ tangent to the path of motion

The restoring force $mg\sin\theta$ still acts towards the mean position O and due to this force the bob again starts moving towards the mean position O. In this way, the bob continues its to and fro motion about the mean position O.

It is clear from the above discussion that the speed of the bob increases while moving from point A to O due to the restoring force which acts towards O. Therefore, acceleration of the bob is also directed towards O. Similarly, when the bob moves from O to B, its speed decreases due to restoring force which again acts towards O. Therefore, acceleration of the bob is again directed towards O. It follows that the acceleration of the bob is always directed towards the mean position O. Hence the motion of a simple pendulum is SHM.

Time Period



Time period of a pendulum is the time to complete one cycle.

We have the following formula for the time period of a simple pendulum

$$T = 2\pi\sqrt{\frac{\ell}{g}} \qquad \text{......... (10.4)}$$

From the motion of these simple systems, we can define SHM as:

Simple harmonic motion occurs when the net force is directly proportional to the displacement from the mean position and is always directed towards the mean position.

For your information

The period of a pendulum is independent of its mass and amplitude.

In other words, when an object oscillates about a fixed position (mean position) such that its acceleration is directly proportional to its displacement from the mean position and is always directed towards the mean position, its motion is called SHM.

Important features of SHM are summarized as:

i. A body executing SHM always vibrates about a fixed position.

ii. Its acceleration is always directed towards the mean position.

iii. The magnitude of acceleration is always directly proportional to its displacement from the mean

Check Your Understanding

Tell whether or not these motions are examples of simple harmonic motion:
(a) up and down motion of a leaf in water pond (b) motion of a ceiling fan (c) motion of hands of clock (d) motion of a plucked string fixed at both its ends (e) movement of honey bee.

position i.e., acceleration will be zero at the mean position while it will be maximum at the extreme positions.

iv. Its velocity is maximum at the mean position and zero at the extreme positions.

Now we discuss different terms which characterize simple harmonic motion.

Vibration: One complete round trip of a vibrating body about its mean position is called one vibration.

Time Period (T): The time taken by a vibrating body to complete one vibration is called time period.

Frequency (f): The number of vibrations or cycles of a vibrating body in one second is called its frequency. It is reciprocal of time period i.e., $f = 1/T$

Amplitude (A): The maximum displacement of a vibrating body on either side from its mean position is called its amplitude.

Example 10.1: Find the time period and frequency of a simple pendulum 1.0 m long at a location where $g = 10.0\ \text{m s}^{-2}$.

Solution: Given, $\ell = 1.0$ m, $g = 10.0\ \text{m s}^{-2}$.

Using the formula,

$$T = 2\pi\sqrt{\frac{\ell}{g}}$$

By putting the values

$$T = 2\times 3.14 \times \sqrt{\frac{1.0\ \text{m}}{10.0\ \text{m s}^{-2}}} \qquad = 1.99\ \text{s}$$

Frequency of simple pendulum is given by

$$f = 1/T = 1/1.99\ \text{s} = 0.50\ \text{Hz}$$

10.2 DAMPED OSCILLATIONS

Vibratory motion of ideal systems in the absence of any friction or resistance continues indefinitely under the action of a restoring force. Practically, in all systems, the force of friction retards the motion, so the systems do not oscillate indefinitely. The friction reduces the mechanical energy of

For your information

Christian Huygens invented the pendulum clock in 1656. He was inspired by the work of Galileo who had discovered that all pendulums of the same length took the same amount of time to complete one full swing. Huygens developed the first clock that could accurately measure time.

the system as time passes, and the motion is said to be **damped**. This damping progressively reduces the amplitude of the vibration of motion as shown in Fig. 10.4.

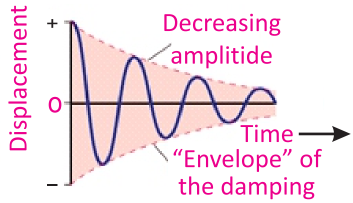


Fig. 10.4: The variation of amplitude with time of damping system

Shock absorbers in automobiles are one practical application of damped motion. A shock absorber consists of a piston moving through a liquid such as oil (Fig.10.5). The upper part of the shock absorber is firmly attached to the body of the car. When the car travels over a bump on the road, the car may vibrate violently. The shock absorbers damp these vibrations and convert their energy into heat energy of the oil. Thus

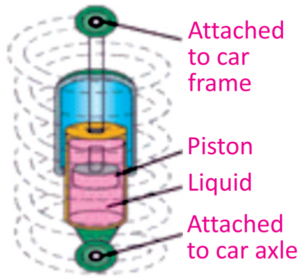


Fig. 10.5: Shock absorber

The oscillations of a system in the presence of some resistive force are damped oscillations.

10.3 WAVE MOTION

Waves play an important role in our daily life. It is because waves are carrier of energy and information over large distances. Waves require some oscillating or vibrating source.
Here we demonstrate the production and propagation of different waves with the help of vibratory motion of objects.

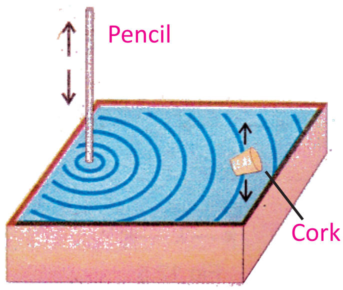


Fig. 10.6: Waves produced by dipping a pencil in a water tub

Activity 10.1: Dip one end of a pencil into a tub of water, and move it up and down vertically (Fig. 10.6). The disturbance in the form of ripples produces water waves, which move away from the source. When the wave reaches a small piece of cork floating near the disturbance, it moves up and down about its original position while the wave will travel outwards. The net displacement of the cork is zero. The cork repeats its vibratory motion about its mean position.

Activity 10.2: Take a rope and mark a point P on it. Tie one end of the rope with a support and stretch the rope by holding its other end in your hand (Fig. 10.7). Now, flipping the rope up and down regularly will set up a wave in the rope which will travel towards the fixed end. The point P on the rope will start vibrating up and down as the wave passes across it. The motion of point P will be perpendicular to the direction of the motion of wave.

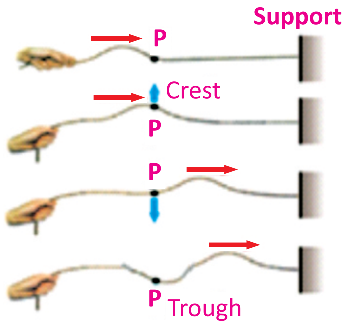


Fig. 10.7: Waves produced in a rope

From the above simple activities, we can define wave as:

A wave is a disturbance in the medium which causes the particles of the medium to undergo vibratory motion about their mean position in equal intervals of time.

There are two categories of waves:

1. Mechanical waves
2. Electromagnetic waves

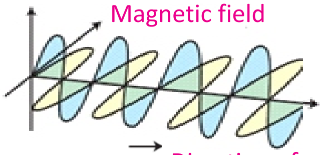
Mechanical Waves: Waves which require any medium for their propagation are called mechanical waves.

Examples of mechanical waves are water waves, sound waves and waves produced on the strings and springs.

Electromagnetic Waves: Waves which do not require any medium for their propagation are called electromagnetic waves.

Radiowaves, television waves, X-rays, heat and light waves are some examples of electromagnetic waves.

For your information



Electromagnetic waves consist of electric and magnetic fields oscillating perpendicular to each other.

Quick Quiz

Do mechanical waves pass through vacuum, that is, empty space?

10.4 TYPES OF MECHANICAL WAVES

Depending upon the direction of displacement of medium with respect to the direction of the propagation of wave itself, mechanical waves may be classified as longitudinal or transverse.

Longitudinal waves can be produced on a spring (slinky) placed on a smooth floor or a long bench. Fix one end of the slinky with a rigid support and hold the other end into your hand. Now give it a regular push and pull quickly in the direction of its length (Fig.10.8).

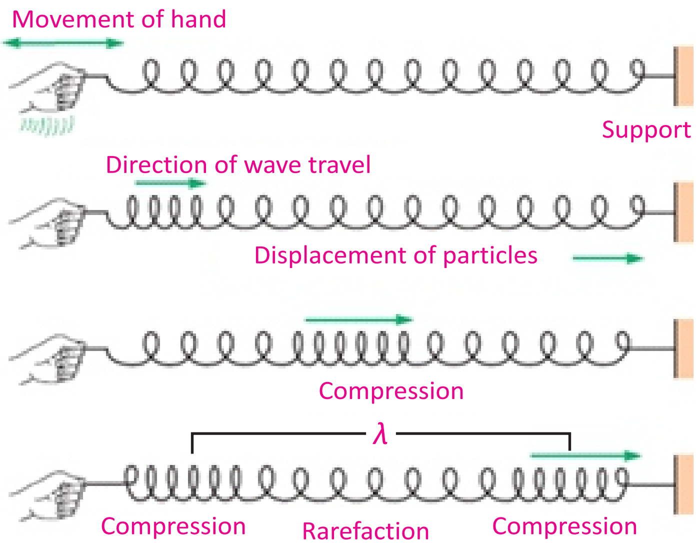


Fig. 10.8: Longitudinal wave on a slinky

A series of disturbances in the form of waves will start moving along the length of the slinky. Such a wave consists of regions called **compressions**, where the loops of the spring are close together, alternating with regions called **rarefactions** (expansions), where the loops are spaced apart. In the regions of compression, particles of the medium are closer together while in the regions of rarefaction, particles of the medium are spaced apart. The distance between two consecutive compressions is called wavelength. The compressions and rarefactions move back and forth along the direction of motion of the wave. Such a wave is called longitudinal wave and is defined as:

In longitudinal waves the particles of the medium move back and forth along the direction of propagation of wave.

We can produce transverse waves with the help of a slinky. Stretch out a slinky along a smooth floor with one end fixed. Grasp the other end of the slinky and move it up and down quickly (Fig.10.9). A wave in the form of alternate crests and troughs will start travelling towards the fixed end. The crests are the highest points while the troughs are the lowest points of the particles of the medium from the mean position. The distance between two consecutive crests or troughs is called

For your Information

Longitudinal waves move faster through solids than through gases or liquids. Transverse waves move through solids at a speed of less than half of the speed of longitudinal waves. It is because the restoring force exerted during this up and down motion of particles of the medium is less than the restoring force exerted by a back and forth motion of particles of the medium in case of longitudinal waves.

wavelength. The crests and troughs move perpendicular to the direction of the wave.

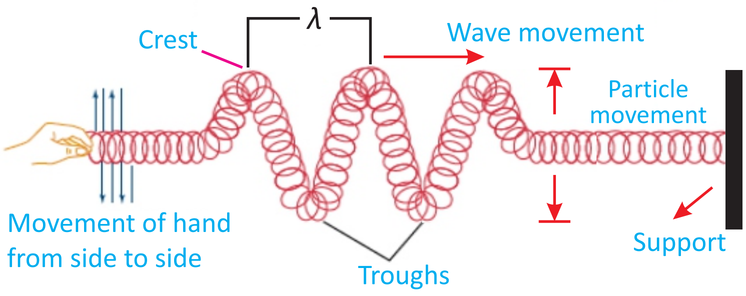


Fig. 10.9: Transverse wave on a slinky

Therefore, transverse waves can be defined as:

In case of transverse waves, the vibratory motion of particles of the medium is perpendicular to the direction of propagation of waves.

Waves on the surface of water and light waves are examples of transverse waves.

WAVES AS CARRIERS OF ENERGY

Energy can be transferred from one place to another through waves. For example, when we shake the stretched string up and down, we provide our muscular energy to the string. As a result, a set of waves can be seen travelling along the string. The vibrating force from the hand disturbs the particles of the string and sets them in motion. These particles then transfer their energy to the adjacent particles in the string. Energy is thus transferred from one place of the medium to the other in the form of wave.

The amount of energy carried by the wave depends on the distance of the stretched string from its rest position. That is, the energy in a wave depends on the amplitude of the wave. If we shake the string faster, we give more energy per second to produce wave of higher frequency, and the wave delivers more energy per second to the particles of the string as it moves forward.

Water waves also transfer energy from one place to another

as explained below:

Activity 10.3: Drop a stone into a pond of water. Water waves will be produced on the surface of water and will travel outwards (Fig. 10.10). Place a cork at some distance from the falling stone. When waves reach the cork, it will move up and down alongwith the motion of the water particles by getting energy from the waves.

Fig. 10.10

This activity shows that water waves like other waves transfer energy from one place to another without transferring matter, i.e., water.

For your information

Generating a high frequency wave, requires more energy per second than to generate a low frequency wave. Thus, a high frequency wave carries more energy than a low frequency wave of the same amplitude.

RELATION BETWEEN VELOCITY, FREQUENCY AND WAVELENGTH

Wave is a disturbance in a medium which travels from one place to another and hence has a specific velocity of travelling. This is called the velocity of wave which is defined by

Velocity = distance/time

$$v = \frac{d}{t}$$

If time taken by the wave in moving from one point to another is equal to its time period T, then the distance covered by the wave will be equal to one wavelength λ, hence we can write:

$$v = \frac{\lambda}{T}$$

But time period T, is reciprocal of the frequency f, i.e., $T = \frac{1}{f}$

Do you know?

Earthquake produces waves through the crust of the Earth in the form of seismic waves. By studying such waves, the geophysicists learn about the internal structure of the Earth and information about the occurrence of future Earth activity.

Therefore, $v = f\lambda$ .... (10.5)

Eq. (10.5) is true both for longitudinal and transverse waves.

Example 10.2: A wave moves on a slinky with frequency of 4 Hz and wavelength of 0.4 m. What is the speed of the wave?

Solution: Given that, $f = 4$ Hz, $\lambda = 0.4$ m

Wave speed $v = f\lambda$

$= (4\ \text{Hz})\,(0.4\ \text{m})$

$v = 1.6\ \text{m s}^{-1}$

10.5 RIPPLE TANK

Ripple tank is a device to produce water waves and to study their characteristics.

This apparatus consists of a rectangular tray having glass bottom and is placed nearly half metre above the surface of a table (Fig. 10.11). Waves can be produced on the surface of water present in the tray by means of a vibrator (paddle).

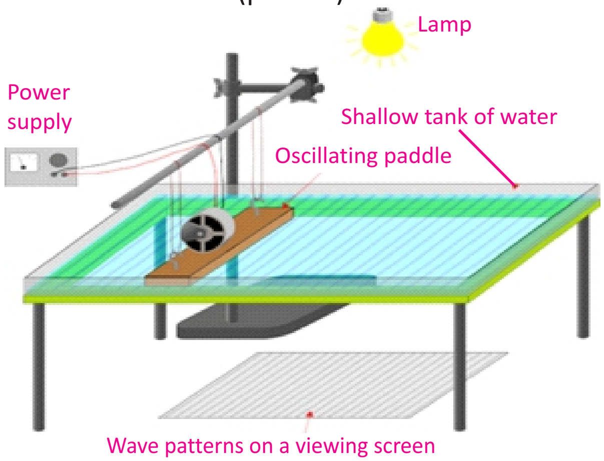


Fig. 10.11: Ripple tank apparatus

This vibrator is an oscillating electric motor fixed on a wooden plate over the tray such that its lower surface just touches the surface of water. On setting the vibrator ON, this wooden plate starts vibrating to generate water waves consisting of straight wavefronts (Fig.10.12). An electric bulb is hung above the tray to observe the image of water waves on the paper or screen. The crests and troughs of the waves appear as bright and dark lines respectively, on the screen.

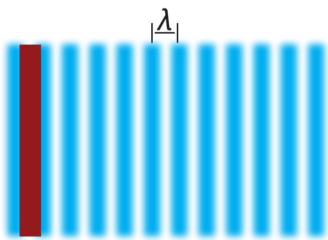


Fig. 10.12: Waves consisting of straight wavefronts

Now we explain the reflection of water waves with the help of ripple tank.

Place a barrier in the ripple tank. The water waves will reflect from the barrier. If the barrier is placed at an angle to the wavefront, the reflected waves can be seen to obey the law of reflection i.e., the angle of the incident wave along the normal will be equal to the angle of the reflected wave (Fig.10.13). Thus, we define reflection of waves as:

When waves moving in one medium fall on the surface of another medium they bounce back into the first medium such that the angle of incidence is equal to the angle of reflection.

Quick Quiz

What do the dark and bright fringes on the screen of ripple tank represent?

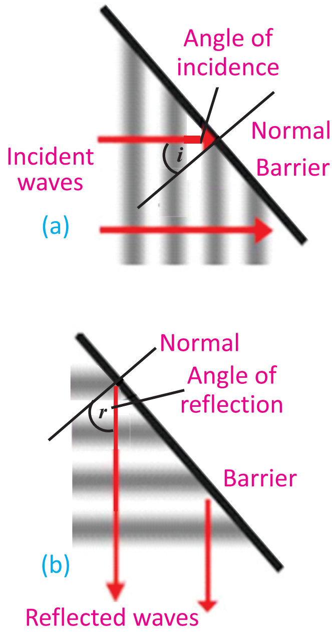


Fig. 10.13: Reflection of water waves from a plane barrier

The speed of a wave in water depends on the depth of water. If a block is submerged in the ripple tank, the depth of water in the tank will be shallower over the block than elsewhere. When water waves enter the region of shallow water their wavelength decreases (Fig.10.14). But the frequency of the water waves remains the same in both parts of water because it is equal to the frequency of the vibrator.

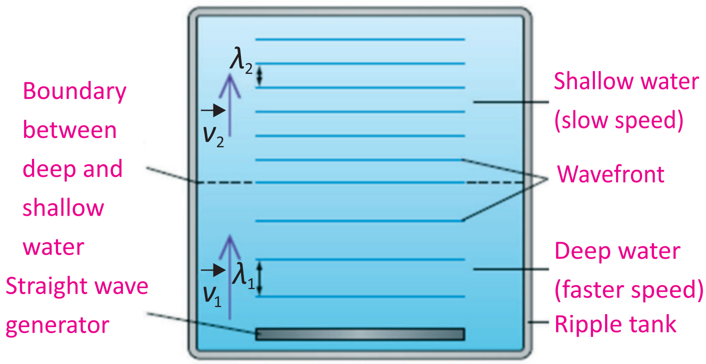


Fig. 10.14

For the observation of refraction of water waves, we repeat the above experiment such that the boundary between the deep and the shallower water is at some angle to the wavefront (Fig. 10.15). Now we will observe that in addition to the change in wavelength, the waves change their direction of propagation as well. Note that the direction of propagation is always normal to the wavefronts. This change of path of water waves while passing from a region of deep water to that of shallower one is called refraction which is defined as:

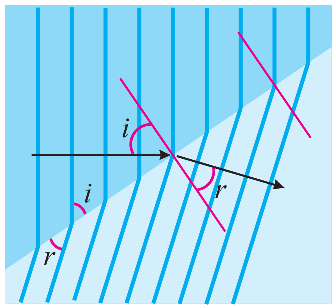


Fig. 10.15: Refraction of water waves

When a wave from one medium enters into the second medium at some angle, its direction of travel changes.

Now we observe the phenomenon of diffraction of water waves. Generate straight waves in a ripple tank and place two obstacles in line in such a way that separation between them is equal to the wavelength of water waves. After passing through a small slit between the two obstacles, the waves will spread in every direction and change into almost semicircular pattern (Fig. 10.16). Diffraction of waves can only be observed clearly if the size of the obstacle is comparable with the wavelength of the wave. Fig.10.17 shows the diffraction of waves while passing through a slit with size larger than the wavelength of the wave. Only a small diffraction occurs near the corners of the obstacle.

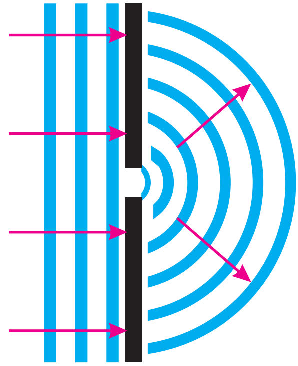


Fig.10.16: Diffraction of water waves through a small slit

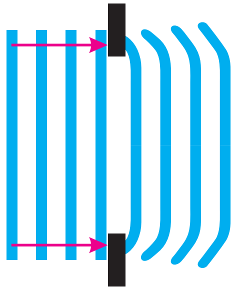


Fig.10.17: Diffraction of water waves through a large slit

The bending or spreading of waves around the sharp edges or corners of obstacles or slits is called diffraction.

Example 10.3: A student performs an experiment with waves in water. The student measures the wavelength of a wave to be 10 cm. By using a stopwatch and observing the oscillations of a floating ball, the student measures a frequency of 2 Hz. If the student starts a wave in one part of a tank of water, how long will it take the wave to reach the opposite side of the tank 2 m away?

Solution:

(1) We are given the frequency, wavelength, and distance.

(2) We have to calculate the time, the wave takes to move a distance of 2 m.

(3) The relationship between frequency, wavelength, and speed is $v = f\lambda$. The relationship between time, speed, and distance is $v = d/t$

(4) Rearrange the speed formula to solve for the time: $t = d/v$

The speed of the wave is the frequency times the wavelength.

$$v = f\lambda = (2\ \text{Hz})(0.1\ \text{m}) = 0.2\ \text{m s}^{-1}.$$

Use this value to calculate the time:

$$t = 2\ \text{m}/0.2\ \text{m s}^{-1} = 10\ \text{s}$$

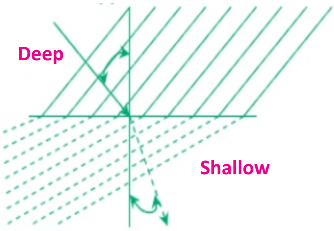


Fig.10.18

ACTIVITY

Study **Fig. 10.18** to answer the following questions:

1. What happens to the direction of wave when water waves pass from deep to shallow part of the water?

2. Are the magnitudes of angle of incidence and angle of refraction equal?

3. Which will be greater?

SUMMARY

- Simple harmonic motion (SHM) is a to and fro oscillatory motion in which acceleration of the body is directly proportional to the displacement of the body from the mean position and is always directed towards the mean position.
- The motion of a mass attached to a spring, simple pendulum and that of a ball inside a bowl is SHM.
- Time taken by the simple pendulum to complete one cycle is called its time period. It depends upon the length of the pendulum and is independent of the mass and amplitude of the pendulum.
- The number of cycles completed in one second is called frequency of a vibrating body. It is reciprocal of time period.
- The maximum displacement from mean position of a body performing SHM is called amplitude.
- Wave is a phenomenon of transferring energy from one place to another without the transfer of matter.
- Mechanical waves are those waves which require some medium for their propagation.
- Electromagnetic waves do not require any medium for their propagation.
- Transverse waves are the mechanical waves in which particles of the medium vibrate about their mean position perpendicular to the direction of propagation of the waves.
- Compressional (longitudinal) waves are the mechanical waves in which particles of the medium vibrate about their mean position along the direction of propagation of the waves.
- The speed (v) of a wave is equal to the product of frequency (f) and wavelength (λ) i.e., $v = f\lambda$.
- Ripple tank is a device used to produce water waves and to demonstrate different properties of water waves like reflection, refraction and diffraction.
- When a wave travelling from one medium falls on the surface of another medium, it may bounce back into the first medium. This phenomenon is called reflection of waves.
- When waves from one medium enter the second medium at some angle their direction of travel may change. This phenomenon is called refraction of waves. The speed and wavelength of wave change in different media but frequency does not change.
- The bending of waves around obstacles or sharp edges is called diffraction of waves.

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the following choices:

i. Which of the following is an example of simple harmonic motion?
(a) the motion of simple pendulum
(b) the motion of ceiling fan
(c) the spinning of the Earth on its axis
(d) a bouncing ball on a floor

ii. If the mass of the bob of a pendulum is increased by a factor of 3, the period of the pendulum's motion will
(a) be increased by a factor of 2
(b) remain the same
(c) be decreased by a factor of 2
(d) be decreased by a factor of 4

iii. Which of the following devices can be used to produce both transverse and longitudinal waves?
(a) a string (b) a ripple tank
(c) a helical spring (slinky) (d) a tuning fork

iv. Waves transfer
(a) energy (b) frequency
(c) wavelength (d) velocity

v. Which of the following is a method of energy transfer?
(a) conduction (b) radiation
(c) wave motion (d) all of these

vi. In a vacuum, all electromagnetic waves have the same
(a) speed (b) frequency
(c) amplitude (d) wavelength

vii. A large ripple tank with a vibrator working at a frequency of 30 Hz produces 25 complete waves in a distance of 50 cm. The velocity of the wave is
(a) 53 cm s^{-1} (b) 60 cm s^{-1}
(c) 750 cm s^{-1} (d) 1500 cm s^{-1}

viii. Which of the following characteristics of a wave is independent of the others?
(a) speed (b) frequency
(c) amplitude (d) wavelength

ix. The relation between v, f and λ of a wave is
(a) $vf = \lambda$ (b) $f\lambda = v$
(c) $v\lambda = f$ (d) $v = \lambda / f$

REVIEW QUESTIONS

10.1. What is simple harmonic motion? What are the necessary conditions for a body to execute simple harmonic motion?

10.2. Think of several examples of motion in everyday life that are simple harmonic.

10.3. What are damped oscillations. How damping progressively reduces the amplitude of oscillation?

10.4. How can you define the term wave? Elaborate the difference between mechanical and electromagnetic waves. Give examples of each.

10.5. Distinguish between longitudinal and transverse waves with suitable examples.

10.6. Draw a transverse wave with an amplitude of 2 cm and a wavelength of 4 cm. Label a crest and trough on the wave.

10.7. Derive a relationship between velocity, frequency and wavelength of a wave. Write a formula relating velocity of a wave to its time period and wavelength.

10.8. Waves are the means of energy transfer without transfer of matter. Justify this statement with the help of a simple experiment.

10.9. Explain the following properties of waves with reference to ripple tank experiment:

a. Reflection b. Refraction c. Diffraction

10.10. Does increasing the frequency of a wave also increase its wavelength? If not, how are these quantities related?

CONCEPTUAL QUESTIONS

10.1. If the length of a simple pendulum is doubled, what will be the change in its time period?

10.2. A ball is dropped from a certain height onto the floor and keeps bouncing. Is the motion of the ball simple harmonic? Explain.

10.3. A student performed two experiments with a simple pendulum. He/She used two bobs of different masses by keeping other parameters constant. To his/her astonishment the time period of the pendulum did not change! Why?

10.4. What types of waves do not require any material medium for their propagation?

10.5. Plane waves in the ripple tank undergo refraction when they move from deep to shallow water. What change occurs in the speed of the waves?

NUMERICAL PROBLEMS

10.1. The time period of a simple pendulum is 2 s. What will be its length on the Earth? What will be its length on the Moon if $g_m = g_e/6$? where $g_e = 10\ \mathrm{m\,s^{-2}}$.

Ans.(1.02 m, 0.17 m)

10.2. A pendulum of length 0.99 m is taken to the Moon by an astronaut. The period of the pendulum is 4.9 s. What is the value of g on the surface of the Moon?

Ans.(1.63 m s^{-2})

10.3. Find the time periods of a simple pendulum of 1 metre length, placed on Earth and on Moon. The value of g on the surface of Moon is 1/6th of its value on Earth, where g_e is 10 m s^{-2}.

Ans.(2 s, 4.9 s)

10.4. A simple pendulum completes one vibration in two seconds. Calculate its length, when g = 10.0 m s^{-2}. **Ans. (1.02 m)**

10.5. If 100 waves pass through a point of a medium in 20 seconds, what is the frequency and the time period of the wave? If its wavelength is 6 cm, calculate the wave speed.

Ans. (5 Hz, 0.2 s, 0.3 m s^{-1})

10.6. A wooden bar vibrating into the water surface in a ripple tank has a frequency of 12 Hz. The resulting wave has a wavelength of 3 cm. What is the speed of the wave?

Ans. (0.36 m s^{-1})

10.7. A transverse wave produced on a spring has a frequency of 190 Hz and travels along the length of the spring of 90 m, in 0.5 s.

(a) What is the period of the wave?

(b) What is the speed of the wave?

(c) What is the wavelength of the wave?

Ans. (0.01 s, 180 m s^{-1}, 0.95 m)

10.8. Water waves in a shallow dish are 6.0 cm long. At one point, the water moves up and down at a rate of 4.8 oscillations per second.

(a) What is the speed of the water waves?

(b) What is the period of the water waves?

Ans. (0.29 m s^{-1}, 0.21 s)

10.9. At one end of a ripple tank 80 cm across, a 5 Hz vibrator produces waves whose wavelength is 40 mm. Find the time the waves need to cross the tank.

Ans. (4 s)

10.10. What is the wavelength of the radiowaves transmitted by an FM station at 90 MHz? where 1M = 10^6, and speed of radiowave is 3 x 10^8 m s^{-1}. **Ans. (3.33 m)**

Unit 11 SOUND

After studying this unit, students will be able to:

- explain how sound is produced by vibrating sources and that sound waves require a material medium for their propagation.
- describe the longitudinal nature of sound waves (as a series of compressions and rarefactions).
- define the terms pitch, loudness and quality of sound.
- describe the effect of change in amplitude on loudness and the effect of change in frequency on pitch of sound.
- define intensity and state its SI unit.
- describe what is meant by intensity level and give its unit.
- explain that noise is a nuisance.
- describe how reflection of sound may produce echo.
- describe audible frequency range.
- describe the importance of acoustic protection.
- solve problems based on mathematical relations learnt in this unit.

Science, Technology and Society Connections

The students will be able to:

- describe that some sounds are injurious to health.
- describe how knowledge of the properties of sound waves is applied in the design of building with respect to acoustics.
- describe how ultrasound techniques are used in medical and industry.
- explain the use of soft materials to reduce echo sounding in classroom studies, and other public gathering buildings.

We know that vibrations of objects in any medium produce waves. For example, vibrator of ripple tank produces water waves. The medium in this case is liquid, but it can also be a gas or a solid. Now we will discuss another type of waves that we can hear i.e., sound waves.

Physics of Sound

All sounds are produced by the vibrations of objects. Sound is a form of energy that travels in the form of waves from one place to another.

11.1 SOUND WAVES

Like other waves, sound is also produced by vibrating bodies. Due to vibrations of bodies the air around them also vibrates and the air vibrations produce sensation of sound in our ear. For example, in a guitar, sound is produced due to the vibrations of its strings (Fig. 11.1). Our voice results from the vibrations of our vocal chords. Human heart beats and vibrations of other organs like lungs also produce sound waves. Doctors use stethoscope to hear this sound.

For your information

Stethoscopes operate on the transmission of sound from the chest-piece, via air-filled hollow tubes, to the listener's ears. The chest-piece usually consists of a plastic disc called diaphragm. If the diaphragm is placed on the patient's body sounds vibrate the diaphragm, creating acoustic pressure waves which after multiple reflection travel up the tubing to the doctor's ears.

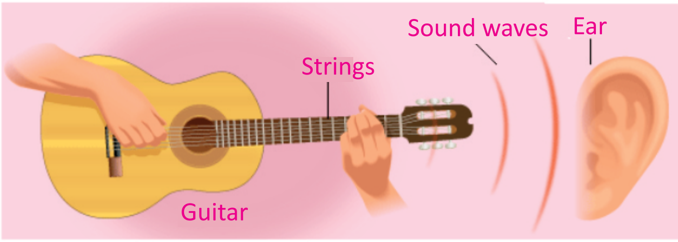


Fig. 11.1: Vibrations of guitar strings produce sound waves

SOUND IS PRODUCED BY A VIBRATING BODY

Activity 11.1: In school laboratories, we use a device called tuning fork to produce a particular sound. If we strike the tuning fork against rubber hammer, the tuning fork will begin to vibrate (Fig. 11.2). We can hear the sound produced by tuning fork by bringing it near our ear. We can also feel the vibrations by slightly touching one of the prongs of the vibrating tuning fork with a plastic ball suspended from a thread (Fig. 11.3). Touch

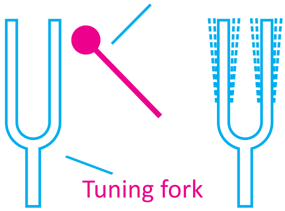


Fig. 11.2: Strike a rubber hammer on a tuning fork

the ball gently with the prong of a vibrating tuning fork. The tuning fork will push the ball because of its vibrations. Now if we dip the vibrating tuning fork into a glass of water, we will see a splash (Fig. 11.4). What does make the water splash?

From this activity, we can conclude that sound is produced by vibrating bodies.

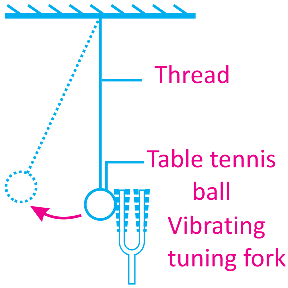


Fig. 11.3: The production of sound waves from a vibrating tuning fork

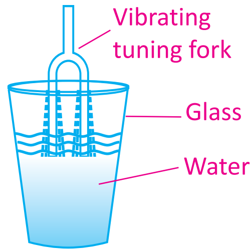


Fig. 11.4

Sound Requires Material Medium for its Propagation

Activity 11.2: Unlike light waves which are electromagnetic in nature and can also pass through vacuum, sound waves require some material medium for their propagation. This can be proved by bell jar apparatus (Fig. 11.5). The bell jar is placed on the platform of a vacuum pump.

An electric bell is suspended in the bell jar with the help of two wires connected to a power supply. By setting ON the power supply, electric bell will begin to ring. We can hear the sound of the bell. Now start pumping out air from the jar by means of a vacuum pump. The sound of the bell starts becoming more and more feeble and eventually dies out, although bell is still ringing. When we put the air back into the jar, we can hear the sound of the bell again. From this activity, we conclude that sound waves can only travel/propagate in the presence of air (medium).

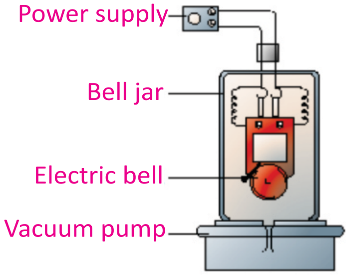


Fig. 11.5: Bell jar apparatus

Longitudinal Nature of Sound Waves

Propagation of sound waves produced by vibrating tuning fork can be understood by a vibrating tuning fork as shown in Fig.11.6. Before the vibration of tuning fork, density of air molecules on the right side is uniform (Fig.11.6-a). When the right prong of tuning fork moves from mean position O to B (Fig.11.6-b), it exerts some pressure on the adjacent layer of air molecules and produces a compression.

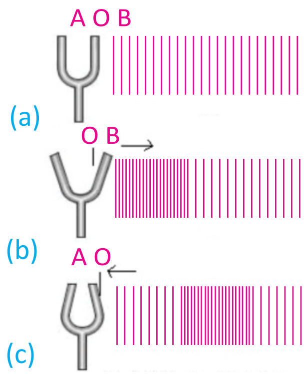


Fig.11.6: Vibrations of tuning fork after striking with a rubber

This compressed air layer in turn compresses the layer next to it and so on. A moment later, the prong begins to move from B towards A (Fig.11.6-c). Now the pressure in the adjacent layer decreases and a rarefaction is produced. This rarefaction is transfered to the air layer next to it and so on. As the tuning fork moves back and forth rapidly, a series of compressions and rarefactions are created in the air. In this way, sound wave propagates through the air.

As in the Fig.11.6, the direction of propagation of sound wave is along the direction of oscillating air molecules. This shows the longitudinal nature of sound waves. Distance between two consecutive compressions or rarefactions is the wavelength of sound wave.

11.2 CHARACTERISTICS OF SOUND

Sounds of different objects can be distinguished on the basis of different characteristics as described below:

Loudness: *Loudness is the characteristic of sound by which loud and faint sounds can be distinguished.*

When we talk to our friends, our voice is low, but when we address a public gathering our voice is loud. Loudness of a sound depends upon a number of factors. Some of them are discussed below:

(a) Amplitude of the vibrating body: The loudness of the sound varies directly with the amplitude of the vibrating body (Fig.11.7). The sound produced by a sitar will be loud if we pluck its wires more violently. Similarly, when we beat a drum forcefully, the amplitude of its membrane increases and we hear a loud sound.

(b) Area of the vibrating body: The loudness of sound also depends upon the area of the vibrating body.

Physics Insight

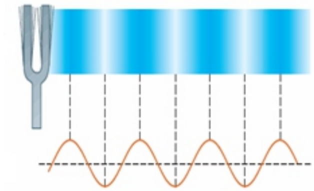


Illustration of longitudinal wave formed by vibrating tuning fork in the air. Compressions are places where air pressure is slightly higher than the surrounding air pressure due to high density of air particles. While rarefactions are the regions correspond to low air pressure due to low density of air particles.

Quick Quiz

Identify which part of these musical instruments vibrates to produce sound:
(a) electric bell (b) loud speaker (c) piano (d) violin (e) flute.

Self Assessment

1. Explain how sound is produced by a school bell.
2. Why are sound waves called mechanical waves?
3.Suppose you and your friend are on the Moon. Will you be able to hear any sound produced by yourfriend?

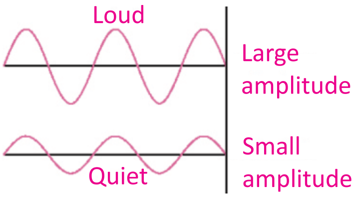


Fig. 11.7: Variation of loudness with amplitude

For example, sound produced by a large drum is louder than that by small one because of its large vibrating area. If we strike a tuning fork on a rubber pad, a feeble sound will be heard. But if the vibrating tuning fork is placed vertically on the surface of a bench, we will hear a louder sound. From this, we can conclude that the loudness increases with the area of the vibrating body and vice versa.

(c) Distance from the vibrating body: Loudness of sound also depends upon the distance of the vibrating body from the listener. It is caused by the decrease in amplitude due to increase in distance.

Loudness also depends upon the physical condition of the ears of the listener. A sound appears louder to a person with sensitive ears than to a person with defective ears. However, there is a characteristic of sound which does not depend upon the sensitivity of the ear of the listener and it is called intensity of sound.

Pitch: ***Pitch is the characteristic of sound by which we can distinguish between a shrill and a grave sound.***

It depends upon the frequency. A higher pitch means a higher frequency and vice versa. The frequency of the voice of ladies and children is higher than that of men. Therefore, the voice of ladies and children is shrill and of high pitch. The relationship between frequency and pitch is illustrated in Fig. 11.8.

Quality: ***The characteristic of sound by which we can distinguish between two sounds of same loudness and pitch is called quality.***

While standing outside a room, we can distinguish between the notes of a piano and a flute being played inside the room. This is due to the difference in the quality of these notes.

Figure 11.9 shows the waveform of the sound produced by a tuning fork, flute and clarinet. The loudness and the pitch of

For your information

Thin-walled glass goblets can vibrate when hit by sound waves. This is due to a phenomenon of sound known as resonance. Some singers can produce a loud note of particular frequency such that it vibrates the glass so much that it shatters.

Interesting information

Some people use silent whistle to call dogs whose frequency lies between 20,000 Hz to 25,000 Hz. It is silent for human but not for dogs because the audible frequency range for dogs is much higher.

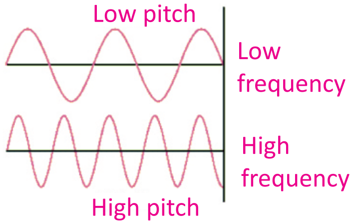


Fig 11.8: Variation of pitch with frequency

For your information

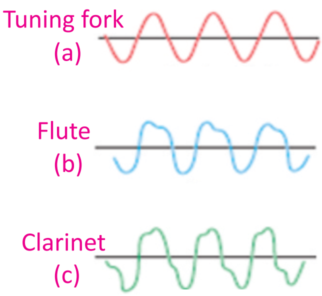


Fig 11.9: Sound waveforms produced by (a) a tuning fork, (b) a flute, and (c) a clarinet, are all at approximately the same frequency. Pressure is plotted vertically, time

these three sounds are the same but their waveforms are different. So their quality is different and they can be distinguished from each other.

Intensity

The sound waves transfer energy from the sounding body to the listener. The intensity of sound depends on the amplitude of sound wave and is defined as:

Sound energy passing per second through a unit area held perpendicular to the direction of propagation of sound waves is called intensity of sound.

Intensity is a physical quantity and can be measured accurately. The unit of intensity of sound is watt per square metre ($W\ m^{-2}$).

Sound Intensity Level

The human ear responds to the intensities ranging from $10^{-12}\ W\ m^{-2}$ to more than $1\ W\ m^{-2}$ (which is loud enough to be painful). Because the range is so wide, intensities are scaled by factors of ten. The barely audible and the faintest intensity of sound i.e., $10^{-12}\ W\ m^{-2}$ is taken as reference intensity, called zero bel (a unit named after Alexander Graham Bell).

The loudness of a sound depends not only on the intensity of sound but also on the physical conditions of the ear. The human ear is more sensitive to some frequencies rather than the others.

The loudness (L) of a sound is directly proportional to the logarithm of intensity i.e.,

$$L \quad \log I$$

$$L = K \log I \qquad .... \ (11.1)$$

where K is a constant of proportionality.

Let L_o be the loudness of the faintest audible sound of intensity I_o and L be the loudness of an unknown sound of intensity I, then by Eq. (11.1), we can write

$$L_o = K \log I_o \qquad .... \ (11.2)$$

Subtracting Eq. (11.2) from Eq. (11.1), we get

Quick Quiz

1. Why the voice of women is more shrill than that of men?

2. Which property of sound wave determines its:
(a) loudness (b) pitch?

3. What would happen to the loudness of sound with increase in its frequency?

Do you know?

Frequency of tuning fork depends on the mass of its prongs. The greater the mass, the lower the frequency of vibration which means the lower the pitch.

For your information

A sound wave with a frequency of 3500 Hz and an intensity of 80 dB sounds about twice as loud to us as a sound of 125 Hz and 80 dB. It is because our ears are more sensitive to the 3500 Hz sound than to the 125 Hz. Therefore intensity by itself does not mean loudness. Loudness is how our ears detect and our brain perceives the intensity of sound waves.

$$L - L_o = K(\log I - \log I_o) = K \log \frac{I}{I_o}$$

This difference, ($L - L_o$), between the loudness L of an unknown sound and the loudness L_o is called the intensity level of the unknown sound. Therefore, the intensity level of an unknown sound is given by

$$\text{Intensity level} = K \log \frac{I}{I_o} \qquad \text{..........} \qquad (11.3)$$

The value of K depends not only on the units of I and I_o but also on the unit of intensity level. If intensity I of any unknown sound is 10 times greater than the intensity I_o of the faintest audible sound i.e., $I = 10I_o$ and the intensity level of such a sound is taken as unit, called bel, the value of K becomes 1. Therefore, using $K = 1$, Eq. (11.3) becomes

$$\text{Intensity level} = \log \frac{I}{I_o} \text{ (bel)} \qquad \text{..........} \qquad (11.4)$$

bel is a very large unit of intensity level of a sound. Generally, a smaller unit called decibel is used. Decibel is abbreviated as (dB). It must be remembered that 1 bel is equal to 10 dB. If the intensity level is measured in decibels, Eq. (11.4) becomes

$$\text{Intensity level} = 10 \log \frac{I}{I_o} \text{ (dB)} \qquad \text{..........} \qquad (11.5)$$

Using Eq. (11.5), we can construct a scale for measuring the intensity level of sound. Such scale is known as "decibel scale". The intensity level of different sounds in decibel is given in Table 11.1.

Example 11.1: Calculate the intensity levels of the (a) faintest audible sound (b) rustling of leaves.

Solution: (a) Intensity level of faintest audible sound can be calculated by substituting $I = I_o = 10^{-12}$ Wm^{-2} in Eq. (11.5). Therefore,

$$\text{Intensity level of faintest audible sound} = 10 \log \frac{10^{-12}}{10^{-12}} \text{ dB}$$
$$= 0 \text{ dB}$$

(b) As the intensity of the rustle of leaves is $I = 10^{-11}$ W m^{-2},

Table 11.1

Sources of Sound	Intensity (Wm^{-2})	Intensity level (dB)
Nearby jet airplane	10^{3}	150
Jackhammer/Fast train	10^{1}	130
Siren	10^{0}	120
Lawn mover	10^{-2}	100
Vacuum cleaner	10^{-5}	70
Mosquito buzzing	10^{-8}	40
Whisper	10^{-9}	30
Rustling of leaves	10^{-11}	10
Faintest audible sound i.e., Threshold	10^{-12}	0

For your information

Logarithmic scale	Linear scale
Decibels (dB)	**Amplitude (m)**
0	1
20	10
40	100
60	1,000
80	10,000
100	1000,000
120	1,000,000

The decibel scale is a *logarithmic* measure of the amplitude of sound waves. In a logarithmic scale, equal intervals correspond to multiplying by 10 instead of adding equal amounts.

therefore,

Intensity level due to rustling of leaves $= 10 \log 10^{-11}/10^{-12}$ dB

$= 10 \log 10$ dB

$= 10$ dB

11.3 REFLECTION (ECHO) OF SOUND

When we clap or shout near a reflecting surface such as a tall building or a mountain, we hear the same sound again a little later. What causes this? This sound which we hear is called an echo and is a result of reflection of sound from the surface.

When sound is incident on the surface of a medium it bounces back into the first medium. This phenomenon is called echo or reflection of sound.

The sensation of sound persists in our brain for about 0.1 s. To hear a clear echo, the time interval between our sound and the reflected sound must be at least 0.1 s. If we consider speed of sound to be 340 ms^{-1} at a normal temperature in air, we will hear the echo after 0.1 s. The total distance covered by the sound from the point of generation to the reflecting surface and back should be at least $340 \text{ m s}^{-1} \times 0.1 \text{ s} = 34.0$ m. Thus, for hearing distinct echoes, the minimum distance of the obstacle from the source of sound must be half of this distance, i.e., 17 m. Echoes may be heard more than once due to successive or multiple reflections.

Activity 11.3: Take two identical plastic pipes of suitable length, as shown in Fig. 11.10. (We can make the pipes using chart paper).

- Arrange the pipes on a table near a wall.
- Place a clock near the open end of one of the pipes and try to hear the sound of the clock through the other pipe.
- Adjust the position of the pipes so that you can hear the sound of the clock clearly.
- Now, measure the angles of incidence and reflection and see the relationship between the angles.

Interesting information

A blue whale's 180 dB rumble is the loudest animal sound ever recorded. Whale sounds also appear to be a part of a highly evolved communication system. Some whales are thought to communicate over hundreds and may be thousands of kilometres. This is possible, in part, because sound waves travel five times faster in water than in air. In addition, the temperature characteristics of ocean water — decrease in temperature with depth — create a unique sound phenomenon.

Do you know?

Elephants use low frequency sound waves to communicate with one another. Their large ears enable them to detect these low frequency sound waves, which have relatively long wavelengths. Elephants can effectively communicate in this way, even when they are separated by many kilometres.

- Lift the pipe on the right vertically to a small height and observe what happens.

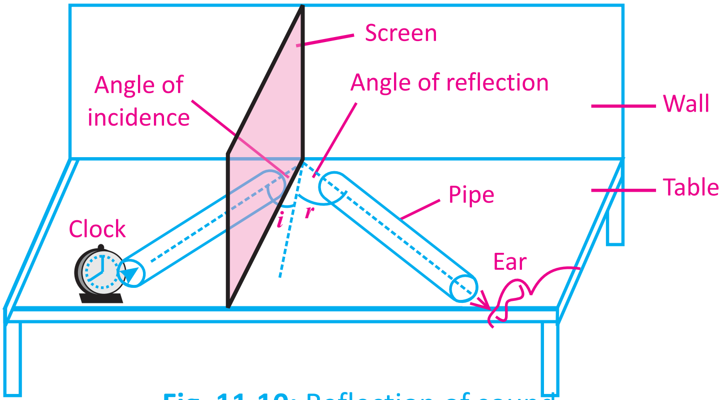
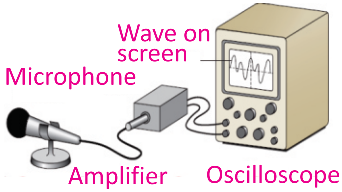


Fig. 11.10: Reflection of sound

For your information



By using an oscilloscope, you can "see" sound waves.

11.4 SPEED OF SOUND

Sound waves can be transmitted by any medium containing particles that can vibrate. They cannot pass through vacuum. However, the nature of the medium will affect the speed of the sound waves. In general, the speed of sound in a liquid is five times that in gases; the speed of sound in solid is about fifteen times that in gases. The speed of sound in air is affected by changes in some physical conditions such as temperature, pressure and humidity etc.

The speed of sound in air is 343 m s^{-1} at one atmosphere of pressure and room temperature (21°C). The speed varies with temperature and humidity. The speed of sound in solids and liquids is faster than in air. Following relation can be used to find the speed of sound:

$$v = f\lambda \quad \text{........ (11.6)}$$

where v is the speed, f is the frequency and λ is the wavelength of sound wave.

Table 11.1
Speed of sound in various media

Medium	Speed (m s^{-1})
Gases	
Air(0°C)	331
Air (25°C)	346
Air(100°C)	386
Hydrogen (0°C)	1290
Oxygen (0°C)	317
Helium (0°C)	972
Liquids at 25°C	
Distilled water	1498
Sea water	1531
Solids 25°C	
Wood	2000
Aluminium	6420
Brass	4700
Nickel	6040
Iron	5950
Steel	5960
Flint Glass	3980

Example 11.2: Calculate the frequency of a sound wave of speed 340 m s^{-1} and wavelength 0.5 m.

Solution: Given that; speed of waves $v = 340\ \text{m s}^{-1}$

Wavelength $\lambda = 0.5\ m$

Using the formula $v = f\ \lambda$

Putting the values

$$f = 340\ m\ s^{-1} / 0.5\ m = 680\ Hz$$

Measuring Speed of Sound by Echo Method

Apparatus: Measuring tape, stopwatch, flat wall that can produce a good echo.

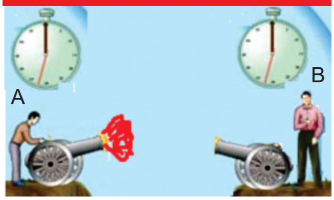
Procedure:

1. Use the tape to measure a distance of 50 metres from the wall.
2. Now clap your hands in front of the wall at a distance of 50 metres and check if you can clearly hear an echo from the wall. Make sure the echo is not coming from any other wall in the area. The time taken by the sound to travel 100 metres is the time difference between the clap and the echo.
3. Now restart the clapping and start the stopwatch at the first clap. Count the number of claps, and stop the clapping and the stopwatch when you hear the echo of the 10th clap (say).
4. Now find the average time for 10 claps. After calculating the time interval t between claps and using the formula $S = vt$, we can calculate the speed of the sound.

Example 11.3: Flash of lightning is seen 1.5 seconds earlier than the thunder. How far away is the cloud in which the flash has occurred? (speed of sound = $332\ m\ s^{-1}$).

Solution: Given that, time $t = 1.5\ s$, speed of sound $v = 332\ m\ s^{-1}$.
Therefore, distance of the cloud $S = vt = 1.5\ s \times 332\ m\ s^{-1} = 498\ m$.

Do you know?



The speed of sound in air was first accurately measured in 1738 by members of the French Academy. Two cannons were set up on two hills approximately 29 km apart. By measuring the time interval between the flash of a cannon and the "boom", the speed of sound was calculated. Two cannons were fired alternatively to minimize errors due to the wind and to delayed reactions in the observers. From their observations, they deduced that sound travels at about $336\ m\ s^{-1}$ at $0^{0}C$.

11.5 NOISE POLLUTION

We enjoy the programmes on radio or television by hearing sounds of different qualities. In musical programmes, we hear sound produced by musical instruments such as flute, harmonium, violin, drum etc. Sound of these instruments has pleasant effect on our ears. Such sounds which are pleasant to

our ears are called musical sounds. However, some sounds produce unpleasant effects on our ears such as sound of machinery, the slamming of a door, and sounds of traffic in big cities. Sound which has jarring and unpleasant effect on our ears is called noise. Noise corresponds to irregular and sudden vibrations produced by some sounds.

Noise pollution has become a major issue of concern in big cities. Noise is an undesirable sound that is harmful for health of human and other species. Transportation equipment and heavy machinery are the main sources of noise pollution. For example, noise of machinery in industrial areas, loud vehicle horns, hooters and alarms. Noise has negative effects on human health as it can cause conditions such as hearing loss, sleep disturbances, aggression, hypertension, high stress levels. Noise can also cause accidents by interfering with communication and warning signals.

A safe level of noise depends on two factors: the level (volume) of the noise; and the period of exposure to the noise. The level of noise recommended in most countries is usually 85-90 dB over an eight-hour workday. Noise pollution can be reduced to acceptable level by replacing the noisy machinery with environment friendly machinery and equipments, putting sound-reducing barriers, or using hearing protection devices.

Activity 11.4: Develop an action plan to help you address any problem(s) with noise in your workplace considering the following points:

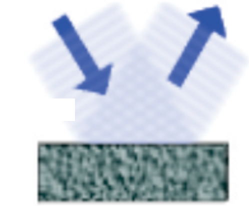
1. Describe the problem(s).
2. What are the sources of the problem(s)?
3. Who are the people being affected?
4. Your suggestions for the solution.

11.6 IMPORTANCE OF ACOUSTICS

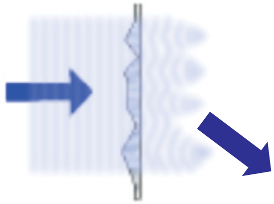
The technique or method used to absorb undesirable sounds by soft and porous surfaces is called acoustic protection.

Reflection of sound is more prominent if the surface is rigid and smooth, and less if the surface is soft and irregular. Soft,

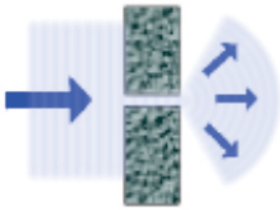
Physics insight



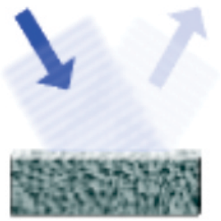
Reflection



Refraction



Diffraction



Absorption

Sound displays all the properties of waves when it interacts with materials and boundaries.

porous materials, such as draperies and rugs absorb large amount of sound energy and thus quiet echoes and softening noises. Thus by using such material in noisy places we can reduce the level of noise pollution. However, if the surface of classrooms or public halls are too absorbent, the sound level may be low for the audience. Sometimes, when sound reflects from the walls, ceiling, and floor of a room, the reflecting surfaces are too reflective and the sound becomes garbled. This is due to multiple reflections called reverberations. In the design of lecture halls, auditorium, or theater halls, a balance must be achieved between reverberation and absorption. It is often advantageous to place reflective surfaces behind the stage to direct sound to the audience.

Generally, the ceilings of lecture halls, conference halls and theatre halls are curved so that sound after reflection may reach all the corners of the hall (Fig 11.11). Sometimes curved sound boards are placed behind the stage so that sound after reflection distributed evenly across the hall (Fig. 11.12).

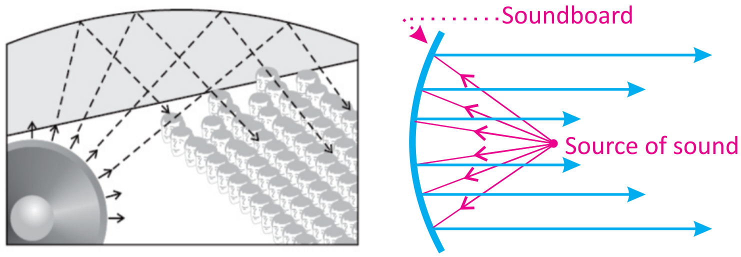
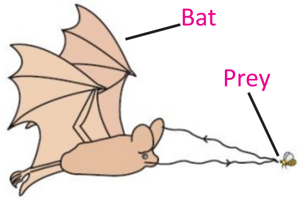


Fig. 11.11: Curved ceiling of a conference hall **Fig. 11.12:** Soundboard used in a big hall

11.7 AUDIBLE FREQUENCY RANGE

We know that sound is produced by a vibrating body. A normal human ear can hear a sound only if its frequency lies between 20Hz and 20,000 Hz. In other words, a human ear neither hears a sound of frequency less than 20 Hz nor a sound of frequency more than 20,000 Hz. Different people have different range of audibility. It also decreases with age. Young children can hear sounds of 20, 000 Hz but old people cannot hear sounds even above 15, 000 Hz.

For your information



The phrase "blind as a bat" is a false statement. Bats have some vision using light, but when placed in pitch-black rooms crisscrossed with fine wires, they can easily fly around and unerringly locate tiny flying insects for food. We usually assume that vision requires light but both bats and dolphins have the ability to "see" using sound waves. Research in science and technology has developed "eyes" that enable humans also to see using sound waves.

For your information

Pilots wear special headphones that reduce the roar of an airplane engine to a quiet hum.

The range of the frequencies which a human ear can hear is called the audible frequency range.

11.8 ULTRASOUND

Sounds of frequency higher than 20, 000 Hz which are inaudible to normal human ear are called ultrasound or ultrasonics.

Uses of Ultrasound

- Ultrasonic waves carry more energy and higher frequency than audible sound waves. Therefore, according to the wave equation $v = f\lambda$, the wavelength of ultrasonic waves is very small and is very useful for detecting very small objects.
- Ultrasonics are utilized in medical and technical fields.
- In medical field, ultrasonic waves are used to diagnose and treat different ailments. For diagnosis of different diseases, ultrasonic waves are made to enter the human body through transmitters. These waves are reflected differently by different organs, tissues or tumors etc. The reflected waves are then amplified to form an image of the internal organs of the body on the screen (Fig.11.13). Such an image helps in detecting the defects in these organs.
- Powerful ultrasound is now being used to remove blood clots formed in the arteries.
- Ultrasound can also be used to get the pictures of thyroid gland for diagnosis purposes.
- Ultrasound is used to locate underwater depths or is used for locating objects lying deep on the ocean floor, etc. The technique is called *SONAR*, *(sound navigation and ranging)*. The sound waves are sent from a transmitter, and a receiver collects the reflected sound (Fig.11.14). The time-lapse is calculated, knowing the speed of sound in water, the distance of the object from the ocean surface can be estimated.

Tidbits

Bats can hear frequencies up to 120,000 Hz. Other animals cannot hear such high-pitched sounds. Mice can hear frequencies up to 100,000 Hz, dogs up to 35,000 Hz, and cats up to 25,000 Hz. Humans hear sounds only upto about 20,000 Hz, but children can usually hear higher-frequency sounds than adults.

Fig. 11.13: Doctors are taking ultrasound test of a patient with an ultrasound machine

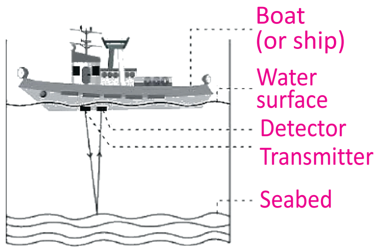


Fig. 11.14: Ultrasonics are used to measure the depth of water by echo method

- SONAR ranging is also used to see the shape and the size of the object.

Cracks appear in the interior of moving parts of high speed heavy machines such as turbines, engines of ships and airplanes due to excessive use. These cracks are not visible from outside but they can be very dangerous. Such cracks can be detected by ultrasonics. A powerful beam of ultrasound is made to pass through these defective parts. While passing, these waves are reflected by the surface of these cracks and flaws. The comparison of the ultrasonic waves reflected from cracks and from the surfaces of these parts can give a clue of the existence of the cracks.

- Germs and bacteria in liquids can also be destroyed by using high intensity ultrasonic waves.

SUMMARY

- Sound is produced by a vibrating body. It travels in the medium from one place to another in the form of compressional waves.
- Loudness is a feature of sound by which a loud and a faint sound can be distinguished. It depends upon the amplitude, surface area and distance from the vibrating body.
- Sound energy flowing per second through unit area held perpendicular to the direction of sound waves is called the intensity of sound. bel is unit of the intensity level of sound, where 1 bel = 10 decibels
- Pitch of the sound is the characteristics of sound by which a shrill sound can be distinguished from a grave one. It depends upon the frequency.
- The characteristics of sound by which two sound waves of same loudness and pitch are distinguished from each other is called the quality of sound.
- The sounds with jarring effect on our ears are called noise and the sounds having pleasant effect on our ears are called musical sounds.
- Noise pollution has become a major issue of concern in some big cities. Any form of sound which disturbs the normal functioning of any natural ecosystem or some human community is the cause of noise pollution.
- Noise pollution can be reduced to acceptable level by replacing the rusty noisy machinery with environment friendly machinery and equipments, putting sound-reducing barriers, or using hearing protection devices.
- The technique or method used to absorb undesirable sound energy by soft and porous surfaces is called acoustic protection. This can be done by using soft, rough and porous materials.

- Human audible frequency range lies between 20 Hz to 20, 000 Hz.
- Sound waves of frequency higher than 20, 000 Hz are called ultrasound while sound waves of frequency lower than 20 Hz are called infrasound.
- Ultrasound is used in many fields of science and technology such as medical, engineering, agriculture. In medical field ultrasound is used to diagnose and treat different ailments. Ultrasound is also used to locate underwater depths or for locating objects lying deep on the ocean floor. The technique is called *SONAR*, an acronym for *sound navigation and ranging*.

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the following choices:

i. Which is an example of a longitudinal wave?
   (a) sound wave (b) light wave
   (c) radiowave (d) water wave

ii. How does sound travel from its source to your ear?
   (a) by changes in air pressure (b) by vibrations in wires or strings
   (c) by electromagnetic wave (d) by infrared waves

iii. Which form of energy is sound?
   (a) electrical (b) mechanical
   (c) thermal (d) chemical

iv. Astronauts in space need to communicate with each other by radio links because
   (a) sound waves travel very slowly in space
   (b) sound waves travel very fast in space
   (c) sound waves cannot travel in space
   (d) sound waves have low frequency in space

v. The loudness of a sound is most closely related to its
   (a) frequency (b) period
   (c) wavelength (d) amplitude

vi. For a normal person, audible frequency range for sound wave lies between
   (a) 10 Hz and 10 kHz (b) 20 Hz and 20 kHz
   (c) 25 Hz and 25 kHz (d) 30 Hz and 30 kHz

vii. When the frequency of a sound wave is increased, which of the following will decrease?
   i. wavelength ii. period iii. amplitude
   (a) i only (b) iii only
   (c) i and ii only (d) i and iii only

REVIEW QUESTIONS

11.1. What is the necessary condition for the production of sound?

11.2. What is the effect of the medium on the speed of sound? In which medium sound travels more faster: air, solid or liquid? Justify your answer.

11.3. How can you prove the mechanical nature of sound by a simple experiment?

11.4. What do you understand by the longitudinal wave? Describe the longitudinal nature of sound waves.

11.5. Sound is a form of wave. List at least three reasons to support the idea that sound is a wave.

11.6. We know that waves manifest phenomenon of reflection, refraction and diffraction. Does sound also manifest these characteristics?

11.7. What is the difference between the loudness and intensity of sound? Derive the relationship between the two.

11.8. On what factors does the loudness of sound depend?

11.9. What do you mean by the term intensity level of the sound? Name and define the unit of intensity level of sound.

11.10. What are the units of loudness? Why do we use logarithmic scale to describe the range of the sound intensities we hear?

11.11. What is difference between frequency and pitch? Describe their relationship graphically.

11.12. Describe the effect of change in amplitude on loudness and the effect of change in frequency on pitch of sound.

11.13. If the pitch of sound is increased, what are the changes in the following?

a. the frequency b. the wavelength

c. the wave velocity d. the amplitude of the wave

11.14. If we clap or speak in front of a building while standing at a particular distance, we rehear our sound after sometime. Can you explain how does this happen?

11.15. What is the audible frequency range for human ear? Does this range vary with the age of people? Explain.

11.16. Explain that noise is a nuisance.

11.17. Describe the importance of acoustic protection.

11.18. What are the uses of ultrasound in medicine?

CONCEPTUAL QUESTIONS

11.1. Why two tin cans with a string stretched between them could be better way to communicate than merely shouting through the air?

11.2. We can recognize persons speaking with the same loudness from their voice. How is this possible?

11.3. You can listen to your friend round a corner, but you cannot watch him/her. Why?

11.4. Why must the volume of a stereo in a room with wall-to-wall carpet be tuned higher than in a room with a wooden floor?

11.5. A student says that the two terms *speed* and *frequency* of the wave refer to the same thing. What is your response?

11.6. Two people are listening to the same music at the same distance. They disagree on its loudness. Explain how this could happen.

11.7. Is there any difference between echo and reflection of sound? Explain.

11.8. Will two separate 50 dB sounds together constitute a100 dB sound? Explain.

11.9. Why ultrasound is useful in medical field?

NUMERICAL PROBLEMS

11.1. A normal conversation involves sound intensities of about 3.0×10^{-6} W m^{-2}. What is the decibel level for this intensity? What is the intensity of the sound for 100 dB?

Ans. (64.8 dB, 0.01 W m^{-2})

11.2. If at Anarkali Bazar Lahore, intensity level of sound is 80 dB, what will be the intensity of sound there?

Ans. (10^{-4} W m^{-2})

11.3. At a particular temperature, the speed of sound in air is 330 m s^{-1}. If the wavelength of a note is 5 cm, calculate the frequency of the sound wave. Is this frequency in the audible range of the human ear? **Ans. (6.6×10^{3} Hz, Yes)**

11.4. A doctor counts 72 heartbeats in 1 min. Calculate the frequency and period of the heartbeats.

Ans. (1.2 Hz, 0.83 s)

11.5. A marine survey ship sends a sound wave straight to the seabed. It receives an echo 1.5 s later. The speed of sound in seawater is 1500 m s^{-1}. Find the depth of the sea at this position. **Ans. (1125 m)**

11.6. A student clapped his hands near a cliff and heard the echo after 5 s. What is the distance of the cliff from the student if the speed of the sound is taken as 346 m s^{-1}?

Ans. (865 m)

11.7. A ship sends out ultrasound that returns from the seabed and is detected after 3.42 s. If the speed of ultrasound through seawater is 1531 m s^{-1}, what is the distance of the seabed from the ship?

Ans. (2618 m)

11.8. The highest frequency sound humans can hear is about 20,000 Hz. What is the wavelength of sound in air at this frequency at a temperature of 20 °C? What is the wavelength of the lowest sounds we can hear of about 20 Hz? Assume the speed of sound in air at 20 °C is 343 m s^{-1}.

Unit 12

GEOMETRICAL OPTICS

After studying this unit. students will be able to:

- describe the terms used in reflection including normal, angle of incidence, angle of reflection and state laws of reflection.
- solve problems of image location by spherical mirrors by using mirror formula.
- define the terminology for the angle of incidence *i* and angle of refraction *r* and describe the passage of light through parallel-sided transparent material.
- solve problems by using the equation sin i /sin $r = n$ (refractive index).
- state the conditions for total internal reflection.
- describe the passage of light through a glass prism.
- describe how total internal reflection is used in light propagation through optical fibres.
- describe how light is refracted through lenses.
- define power of a lens and its unit.
- solve problems of image location by lenses using lens formula.
- define the terms resolving power and magnifying power.
- draw ray diagram of simple microscope and mention its magnifying power.
- draw ray diagram of compound microscope and mention its magnifying power.
- draw ray diagram of a telescope and mention its magnifying power.
- draw ray diagrams to show the formation of images in the normal eye, a short-sighted eye and a long-sighted eye.
- describe the correction of short-sight and long-sight.

Science, Technology and Society Connections

The students will be able to:

- describe the use of spherical mirrors for safe driving, blind turns on hilly roads, dentist mirror.
- describe the use of optical fibres in telecommunications and medical field and state the advantages of their use.
- describe the use of a single lens as a magnifying glass and in a camera, projector and photographic enlarger and draw ray diagrams to show how each forms an image.
- describe the use of lenses/contact lenses for rectifying vision defects of the human eye.
- describe the exploration of the world of micro-organisms by using microscopes and of distant celestial bodies by telescopes.

Light is the main focus of this unit. We shall describe different phenomena of light such as reflection, refraction and total internal reflection. We will learn how images are formed by mirrors and lenses and will discuss working principle of compound microscope and telescope.

12.1 REFLECTION OF LIGHT

Reflection of light is illustrated in Fig. 12.1. When a ray of light from air along the path AO falls on a plane mirror M, it is reflected along the path OB. The ray AO is called incident ray while the ray OB is called reflected ray. The angle between incident ray AO and normal N, i.e.,8 AON is called the angle of incidence represented by ***i***. The angle between the normal and the reflected ray OB, i.e., 8 NOB is called angle of reflection represented by *r.*

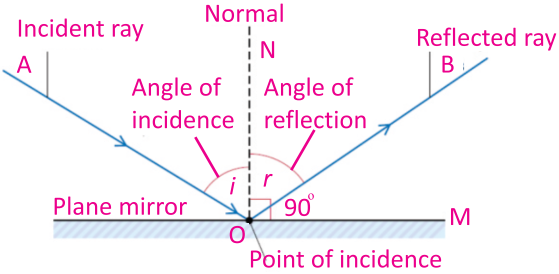


Fig. 12.1: Reflection of light

Now we can define the phenomenon of reflection as:

When light travelling in a certain medium falls on the surface of another medium, a part of it turns back in the same medium.

Laws of Reflection

(i) The incident ray, the normal, and the reflected ray at the point of incidence all lie in the same plane.
(ii) The angle of incidence is equal to the angle of reflection i.e., i = r.

Physics of Light

We see a page of a book because light reflects from each part of the page in all directions, so that some of the light rays from each part of the page enter our eye. Because almost no light is reflected by the printed words, we "see" them as black areas.

For your information

In the early 1700s, there were two ideas about the nature of light: particle nature and wave nature. Newton put forward the idea of corpuscular nature of light. According to him, light consists of tiny, fast-moving particles. Maxwell formulated the wave theory of light. In 1802, Thomas Young proved the wave nature of light experimentally. In 1900, Planck suggested that light consists of small packets of energy called photon. Later on idea of photon was confirmed by experiments. Now we know that light has dual nature; light as well as particle nature.

Types of Reflection

Nature of reflection depends on smoothness of the surface. For example, a smooth surface of silver reflects rays of light in one direction only. The reflection by these smooth surfaces is called ***regular*** reflection (Fig.12.2). Most of the objects in everyday world are not smooth on the microscopic level. The rough surfaces of these objects reflect the rays of light in many directions. Such type of reflection is called ***irregular*** reflection (Fig. 12.3).

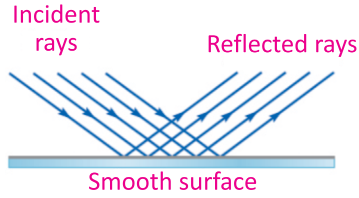


Fig. 12.2: Regular reflection

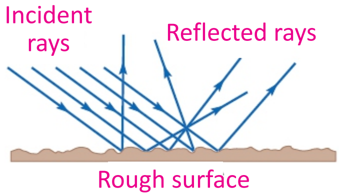
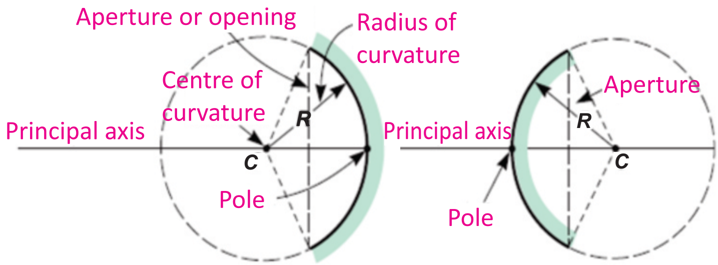


Fig. 12.3: Irregular reflection

12.2 SPHERICAL MIRRORS

A mirror whose polished, reflecting surface is a part of a hollow sphere of glass or plastic is called a spherical mirror. In a spherical mirror, one of the two curved surfaces is coated with a thin layer of silver followed by a coating of red lead oxide paint. Thus, one side of the spherical mirror is opaque and the other side is a highly polished reflecting surface. Depending upon the nature of reflecting surface, there are two types of spherical mirrors as shown in Fig.12.4.



(a) Concave mirror (b) Convex mirror

Fig. 12.4: Types of spherical mirrors

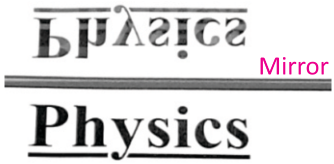
Concave Mirror: A spherical mirror whose inner curved surface is reflecting is called concave mirror. In concave mirror the size of the image depends on the position of the object. Both virtual and real images can be formed by a concave mirror.

Convex Mirror: A spherical mirror whose outer curved surface is reflecting is called convex mirror. In convex mirror the size of the image is always smaller than the object. Only virtual and erect image is formed by a convex mirror.

Pole: It is the midpoint of the curved surface of spherical mirror. It is also called vertex.

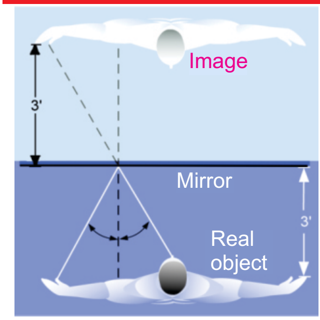
Centre of Curvature (C): A spherical mirror is a part of a

For Your Information



Light rays are reflected in a plane mirror, causing us to see an inverted image.

Do you know?



The image you see in a flat mirror is at the same distance behind the mirror as you are in front of it.

sphere. The centre of this sphere is called centre of curvature.

Radius of Curvature (R): It is the radius of the sphere of which spherical mirror is a part.

Principal Axis: It is the line joining centre of curvature and pole of the spherical mirror.

The Principal focus (*F*): After reflection from a concave mirror, rays of light parallel to the principal axis converge to a point F. This point is called "The Principal Focus" of the mirror (Fig.12.5-a). Hence, Concave mirrors are also called converging mirrors. Since rays actually pass through this point, therefore, it is called real focus.

In the case of a convex mirror, rays parallel to the principal axis after reflection appear to come from a point F situated behind the mirror. In other words rays of light appear to diverge from F. This point is called the principal focus of the convex mirror. Convex mirrors are also called diverging mirrors. The principal focus of a convex mirror is virtual focus because the reflected rays do not actually pass through it but appear to do so (Fig. 12.5-b).

Focal length (*f*): It is the distance from the pole to the principal focus measured along the principal axis (Fig12.5). The focal length is related to the radius of curvature by $f = R/2$. This means that as the radius of curvature is reduced, so too is the focal length of the reflecting surface.

Can you tell?

In this picture you can see clearly the image of a lion formed inside the pond water. Can you tell which phenomenon of physics is involved here ?

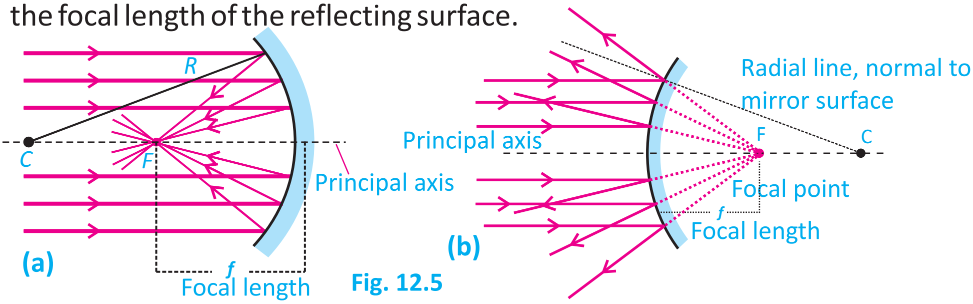
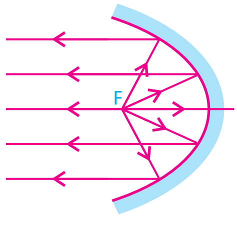


Fig. 12.5

Characteristics of Focus of a Concave and a Convex Mirror

Convex Mirror	Concave Mirror
The Focus lies behind the mirror	The focus is in front of the mirror
The focus is virtual as the rays of light after reflection appear to come from the focus.	The focus is real as the rays of light after reflection converge at the focus.

For your information



Parabolic mirror used in head lights.

Reflection of Light by Spherical Mirrors

Like plane surfaces, spherical surfaces also reflect light following the two laws of reflection as stated for plane

surfaces. Fig.12.6 shows how light is reflected by the spherical surfaces of concave and convex mirrors according to the two laws of reflection.

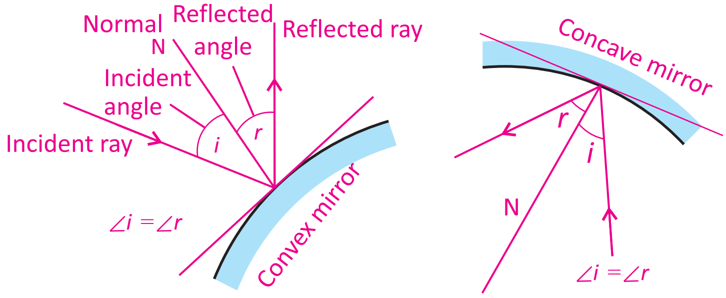


Fig.12.6: Reflection of light by spherical mirrors

Activity12.2: Take a convex mirror or a well polished spoon (using the outside of the spoon, with the convex surface bulging outward), and hold it in one hand. Hold a pencil with its tip in the upright position in the other hand. Try to look at its image in the mirror. Is the image erect or inverted? Is the image smaller or larger in size than the object? Move the pencil away from the mirror. Does the image become smaller or larger? Guess, whether the image will move closer to or farther from the focus?

12.3 IMAGE LOCATION BY SPHERICAL MIRROR FORMULA

How can we tell about the nature of image (whether image is real or imaginary, inverted or erect) formed in a mirror? How can we tell about the size of the image compared with the size of the object? To answer these questions, one method is graphical or ray diagram. But, we can also answer these questions by using a mathematical formula called the mirror formula defined as:

Mirror formula is the relationship between object distance p, image distance q from the mirror and focal length f of the mirror.

Thus we can write mirror formula as:

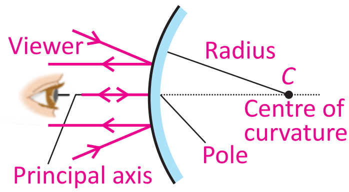
$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \quad .... \quad (12.1)$$

Equation (12.1) is true for both concave and convex mirrors. However, following sign conventions should be

Spoon as mirror

A well polished spoon acts as convex (right) and concave (left) mirrors.

Physics insight



For a convex mirror, focus and centre of curvature lie behind the mirror.

Point to ponder

In large shopping centres, convex mirrors are used for security purposes. Do you know why?

For your information

The focal length of a spherical mirror is one-half of the radius of curvature i.e., $f = R/2$. However, we take the focal length of a convex mirror as negative. It is because the rays appear to come from the focal point behind the mirror. Therefore, for a convex mirror, $f = -R/2$.

followed to apply this equation for solving problems related to mirrors.

Sign Conventions

Quantity	When Positive (+)	When Negative (–)
Object distance p	Real object	Virtual object
Image distance q	Real Image	Virtual image
Focal length f	Concave mirror	Convex mirror

Activity12.3: Take a concave mirror or a well polished spoon (using inside of the spoon with concave surface bulging inward). Hold it in hand towards a distant object, such as the Sun, a building, a tree or a pole. Try to get a sharp, well-focused image of the distant object on the wall or a screen. Measure the distance of the screen from the mirror using a metre scale. Can you find out the rough focal length of the concave mirror? Draw the ray diagram to show the image formation in this situation.

Example 12.1: A convex mirror is used to reflect light from an object placed 66 cm in front of the mirror. The focal length of the mirror is 46 cm. Find the location of the image.

Solution: Given that, $p = 66$ cm and $f = -46$ cm

Using mirror formula,

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p}$$

$$\frac{1}{q} = -\frac{1}{46\text{ cm}} - \frac{1}{66\text{ cm}}$$

$$\frac{1}{q} = -\frac{1}{27\text{ cm}}$$

$$q = -27\text{ cm}$$

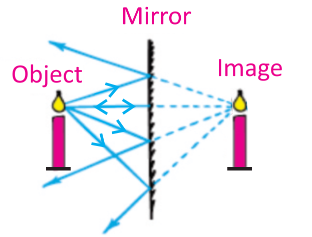
The negative sign indicates that the image is behind the mirror and, therefore, is a virtual image.

Example 12.2: An object is placed 6 cm in front of a concave mirror that has focal length 10 cm. Determine the location of the image.

Physics insight

Note that the word magnification, as used in optics, does not always mean enlargement, because the image could be smaller than the object.

For your information



Ray diagram for the virtual image formation in a plane mirror.

Do you know?

Convex mirrors produce images that are smaller than objects. This increases the view for the observer.

Solution: Given that, $p = 6$ cm and $f = 10$ cm

Using the mirror formula,

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p}$$

$$\frac{1}{q} = \frac{1}{10\text{ cm}} - \frac{1}{6\text{ cm}}$$

$$\frac{1}{q} = -\frac{1}{15\text{ cm}}$$

$$q = -15\text{ cm}$$

The negative sign indicates that the image is virtual i.e., behind the mirror.

12.4 REFRACTION OF LIGHT

If we dip one end of a pencil or some other object into water at an angle to the surface, the submerged part looks bent as shown in Fig.12.7. Its image is displaced because the light coming from the underwater portion of the object changes direction as it leaves the water. This bending of light as it passes from one transparent medium into another is called ***refraction***.

Refraction of light can be explained with the help of Fig.12.8. A ray of light IO travelling from air falls on the surface of a glass block.

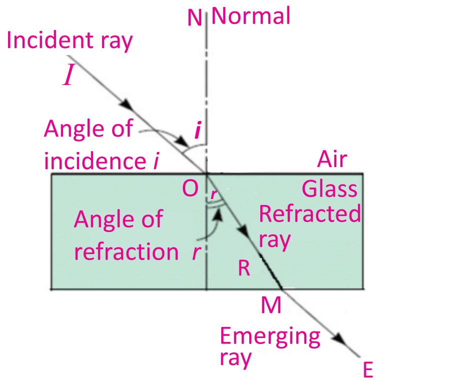
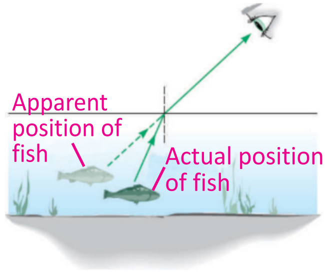


Fig. 12.8: Refraction of light by a glass block

At the air-glass interface, the ray of light IO changes direction and bends towards the normal and travels along the path OR inside the glass block. The rays IO and OR are called the incident ray and the refracted ray respectively. The angle '*i*' made by the incident

Point to ponder



Why the position of fish inside the water seems to be at less depth than that of its actual position?

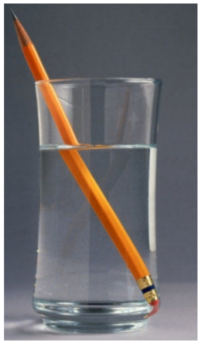
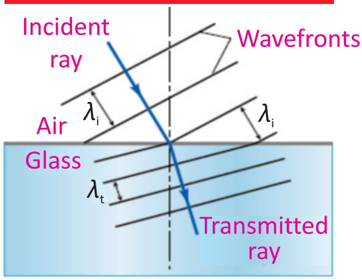


Fig.12.7: Bending of pencil in water due to refraction

Physics insight



In refraction, the speed of light changes due to change in the wavelength. But, frequency and hence the colour of light does not change.

ray with the normal is called angle of incidence. The angle '*r*' made by the refracted ray with the normal is called angle of refraction. When refracted ray leaves the glass, it bends away from the normal and travels along a path ME. Thus

The process of bending of light as it passes from air into glass and vice versa is called refraction of light.

LAWS OF REFRACTION

(i) The incident ray, the refracted ray, and the normal at the point of incidence all lie in the same plane.
(ii) The ratio of the sine of the angle of incidence '*i*' to the sine of the angle of refraction '*r*' is always equal to a constant i.e., $\sin i / \sin r = \text{constant} = n$

where the ratio $\sin i / \sin r$ is known as the refractive index of the second medium with respect to the first medium. So we have

$$\frac{\sin i}{\sin r} = n \quad \ldots\ldots (12.2)$$

It is called Snell's law.

Speed of light in a medium

Refraction of light is caused by the difference in speed of light in different media. For example, the speed of light in air is approximately 3.0×10^8 m s^{-1} However, when light travels through a medium, such as water or glass, its speed decreases. The speed of light in water is approximately 2.3×10^8 m s^{-1}, while in glass, it is approximately 2.0×10^8 m s^{-1}. To describe the change in the speed of light in a medium, we use the term ***index of refraction*** or ***refractive index.***

Refractive Index

The refractive index '*n*' of a medium is the ratio of the speed of light '*c*' in air to the speed '*v*' of light in the medium:

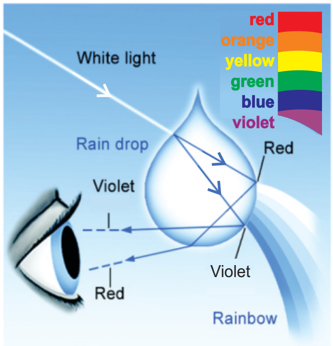
$$\text{Refractive Index} = \frac{\textit{Speed of light in air}}{\textit{Speed of light in medium}}$$

$$\text{or} \quad n = \frac{c}{v} \quad \ldots\ldots\ldots (12.3)$$

For your information

Substance	Index of Refraction (n)
Diamond	2.42
Cubic Zirconia	2.21
Glass (flint)	1.66
Glass(crown)	1.52
Ethyl Alcohol	1.36
Ice	1.31
Water	1.33
Air	1.00

Do you know?



Dispersion of light is due to the variation in refractive index with the colour. Dispersion in drops of water separates the colours of sunlight into a rainbow.

Self Assessment

Whether the bending of light be more or less for a medium with high refractive index?

Example 12.3: A ray of light enters from air into glass. The angle of incidence is 30°. If the refractive index of glass is 1.52, then find the angle of refraction '*r*'.

Solution: Given that, $i = 30^\circ$, $n = 1.52$

Using Snell's law, $\dfrac{\sin i}{\sin r} = n$

$$1.52 \sin r = \sin 30^\circ$$

or $$\sin r = \sin 30^\circ / 1.52$$

$$\sin r = 0.33$$

$$r = \sin^{-1}(0.33)$$

$$r = 19.3^\circ$$

Hence, angle of refraction is 19.3°.

12.5 TOTAL INTERNAL REFLECTION

When a ray of light travelling in denser medium enters into a rarer medium, it bends away from the normal (Fig.12.9-a). If the angle of incidence '*i*' increases, the angle of refraction '*r*' also increases. For a particular value of the angle of incidence, the angle of refraction becomes 90°. The angle of incidence, that causes the refracted ray in the rarer medium to bend through 90° is called critical angle (Fig.12.9-b). When the angle of incidence becomes larger than the critical angle, no refraction occurs. The entire light is reflected back into the denser medium (Fig.12.9-c). This is known as total internal reflection of light.

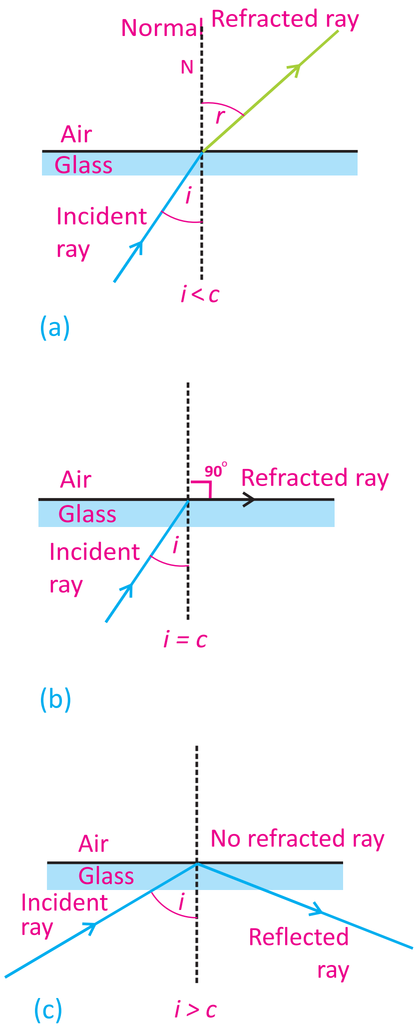


Fig. 12.9: Condition for total internal reflection

Example 12.4: Find the value of critical angle for water (refracted angle = 90°). The refractive index of water is 1.33 and that of air is 1.

Solution: When light enters in air from water, Snell's law becomes

$$\frac{\sin r}{\sin i} = n$$

or $$n \sin i = \sin r$$

$$n \sin i = \sin 90^\circ$$

$$n \sin i = 1$$

But $$n = 1.33$$

Therefore,

$$i = \sin^{-1}[1/1.33]$$

or $$= \sin^{-1}(0.752) = 48.8^\circ$$

$$\text{Critical angle } C = 48.8^\circ$$

Therefore, critical angle of water is 48.8°.

12.6 APPLICATIONS OF TOTAL INTERNAL REFLECTION

Totally Internal Reflecting Prism

Many optical instruments use right-angled prisms to reflect a beam of light through 90° or 180° (by total internal reflection) such as cameras, binoculars, periscope and telescope. One of the angles of a right-angled prism is 90°. When a ray of light strikes a face of prism perpendicularly, it enters the prim without deviation and strikes the hypotenuse at an angle of 45°(Fig.12.10). Since the angle of incidence 45°is greater than critical angle of the glass which is 42°, the light is totally reflected by the prism through an angle of 90°. Two such prisms are used in periscope (Fig.12.11). In Fig.12.12, the light is totally reflected by the prism by an angle of 180°. Two such prisms are used in binoculars (Fig.12.13).

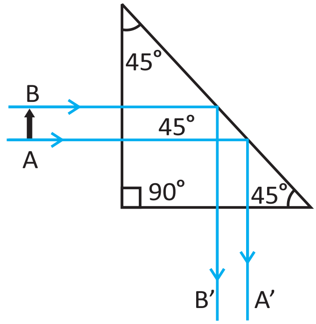


Fig.12.10: Total internal reflection through right angled prism

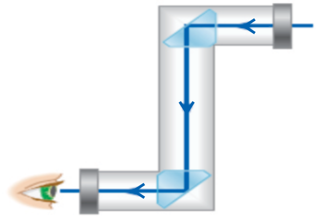


Fig. 12.11: Prism periscope

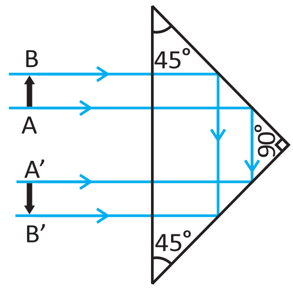


Fig. 12.12

Optical Fibre

Total internal reflection is used in fibre optics which has number of advantages in telecommunication field. Fibre optics consists of hair size threads of glass or plastic through which light can be travelled (Fig. 12.14). The inner part of the fibre optics is called core that carries the light and an outer concentric shell is called cladding. The core is made from glass or plastic of relatively high index of refraction. The cladding is made of glass or plastic, but of relatively low refractive index. Light entering from one end of the core strikes the core-cladding boundary at an angle of incidence greater than critical angle and is reflected back into the core (Fig. 12.14). In this way light travels many kilometres with small loss of energy.

In Pakistan, optical fibre is being used in telephone and advanced telecommunication systems. Now we can listen thousands of phone calls without any disturbance.

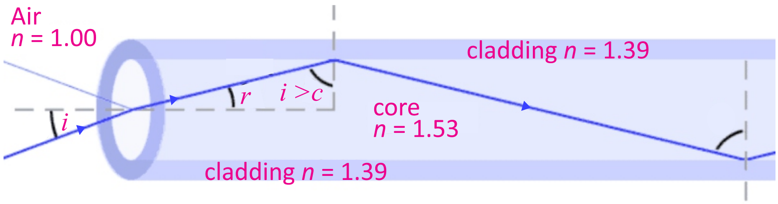


Fig.12.14: Passage of light through optical fibre

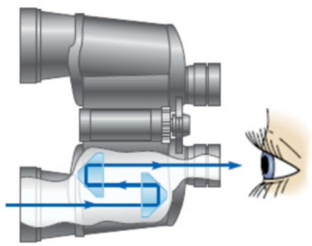


Fig. 12.13: Binoculars

Light Pipe

Light pipe is a bundle of thousands of optical fibres bounded together. They are used to illuminate the inaccessible places by the doctors or engineers. For example, doctors view inside the human body. They can also be used to transmit images from one place to another (Fig. 12.15).

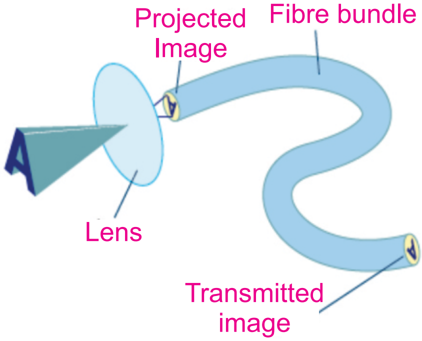


Fig.12.15: A lens and light pipe can be used together to produce a magnified transmitted image of an object

Fig. 12.16: The Doctors are examining a patient with endoscope

Endoscope

An endoscope is a medical instrument used for exploratory diagnostics, and surgical purposes. An endoscope is used to explore the interior organs of the body. Due to its small size, it can be inserted through the mouth and thus eliminates the invasive surgery. The endoscopes used to examine the stomach, bladder and throat are called *Gastroscope*, *C*ystoscope and *B*ronchoscope respectively. An endoscope uses two fibre-optic tubes through a pipe. A medical procedure using any type of endoscope is called endoscopy. The light shines on the organ of patient to be examined by entering through one of the fibre tubes of the endoscope. Then light is transmitted back to the physician's viewing lens through the other fibre tube by total internal reflection (Fig.12.16). Flexible endoscopes have a tiny camera attached to the end. Doctor can see the view recorded by the camera on a computer screen.

12.7 REFRACTION THROUGH PRISM

Prism is a transparent object (made of optical glass) with at least two polished plane faces inclined towards

each other from which light is refracted.

In case of triangular prism (Fig.12.17), the emergent ray is not parallel to the incident ray. It is deviated by the prism from its original path. The incident ray PE makes an angle of incidenace '*i*' at point E and is refracted towards the normal *N* as EF. The refracted ray EF makes an angle '*r*' inside the prism and travels to the other face of the prism. This ray emerges out from prism at point F making an angle 'e'. Hence the emerging ray FS is not parallel to the incident ray PE but is deviated by an angle *D* which is called angle of deviation.

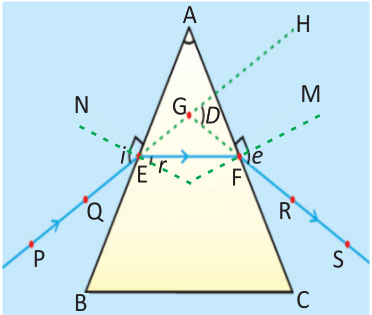
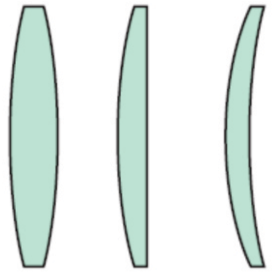


Fig.12.17: Refraction through a triangular glass prism

12.8 LENSES

A lens is any transparent material having two surfaces, of which at least one is curved. Lenses refract light in such a way that an image of the object is formed.

Lenses of many different types are used in optical devices such as cameras, eyeglasses, microscopes, telescopes, and projectors. They also enable millions of people to see clearly and read comfortably.

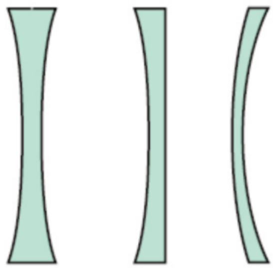


Double convex Plano-convex Concavo-convex

Fig.12.18: Convex lenses

Types of Lenses

There are different types of lenses. The lens which causes incident parallel rays to converge at a point is known as *convex* or *converging* lens. This lens is thick at the centre but thin at the edges (Fig.12.18). Another type of lens causes the parallel rays of light to diverge from a point. This is called concave or diverging lens. This lens is thin at the centre and thick at the edges (Fig.12.19).



Double concave Plano-concave Convexo-concave

Fig.12.19: Concave lenses

Lens Terminology

Principal Axis: Each of the two surfaces of a spherical lens is a section of a sphere. The line passing through the two centres of curvatures of the lens is called *principal axis* (Fig. 12.20).

Optical Centre, C: A point on the principal axis at the centre of lens is called *optical centre* (Fig. 12.20).

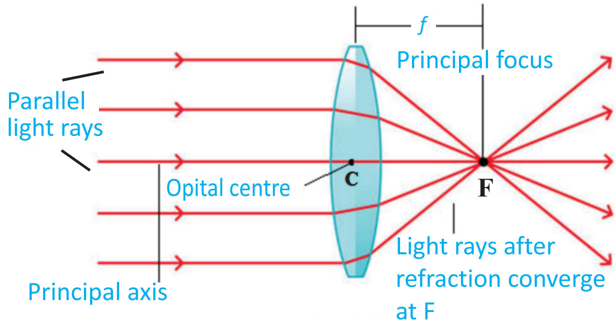


Fig. 12.20: Convex lens

Principal Focus, F: The light rays travelling parallel to the principal axis of a convex lens after refraction meet at a point on the principal axis, called principal *focus* or focal point F. Hence, convex lens is also called converging lens. For a concave lens, the parallel rays appear to come from a point behind the lens called *principal focus* F (Fig. 12.21). Hence concave lens is also called diverging lens.

Focal Length, *f* : This is the distance between the optical centre and the principal focus (Fig. 12.21).

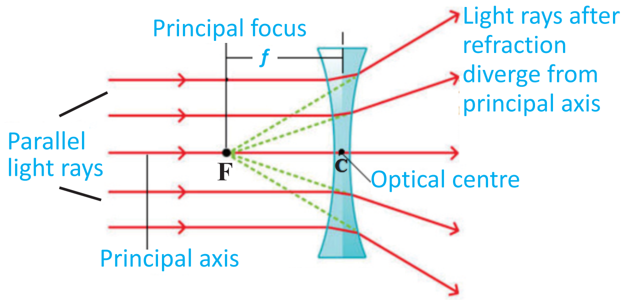
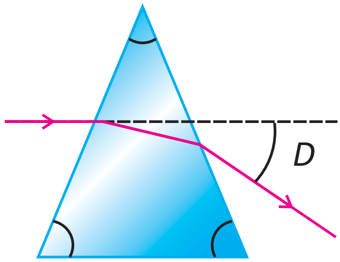


Fig. 12.21: Concave lens

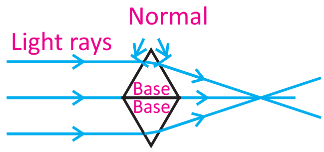
Activity 12.4: Place a convex lens in front of a white screen and adjust its position until a sharp image of a distant object is obtained on the screen. For example, we can do this experiment before an open window to get the image of window on a wall or screen (Fig.12.22). Measure the distance between the lens and the screen. This is the approximate focal length of the lens. Explain. (**Hint:** Make a ray diagram). What is the nature of image?

Refraction through prism



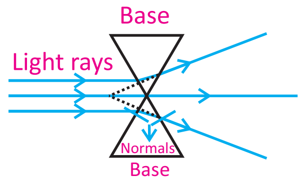
When light passes through prism it deviates from its original path due to refraction.

For your information



System of two prisms resembles a convex lens

For your information



System of two prisms resembles a concave lens

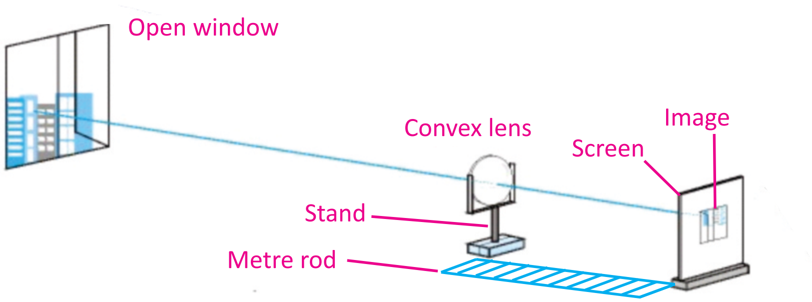


Fig.12.22: Approximate method of finding focal length of a convex lens

Power of a Lens

Power of a lens is defined as the reciprocal of its focal length in metres. Thus

Power of a lens = P = 1 / focal length in metres

The SI unit of power of a lens is "Dioptre", denoted by a symbol D. If f is expressed in metres so that 1 D = 1 m^{-1}. Thus, 1 Dioptre is the power of a lens whose focal length is 1 metre. Because the focal length of a convex lens is positive, therefore, its power is also positive. Whereas the power of a concave lens is negative, for it has negative focal length.

For your information

Dioptres are handy to use because if two thin lenses are placed side by side, the total power is simply the sum of the individual powers. For example, an ophthalmologist places a 2.00 dioptre lens next to 0.35 dioptre lens and immediately knows that the power of the combination is 2.35 dioptres.

12.9 IMAGE FORMATION BY LENSES

In mirrors images are formed through reflection, but lenses form images through refraction. This is explained with the help of ray diagrams as follows:
Image formation in convex lens can be explained with the help of three principal rays shown in Fig.12.23

1. The ray parallel to the principal axis passes through the focal point after refraction by the lens.
2. The ray passing through the optical centre passes straight through the lens and remains undeviated.
3. The ray passing through the focal point becomes

Remember it

When dealing with diverging lenses, you must be careful not to omit the negative sign associated with the focal length and the image position.

parallel to the principal axis after refraction by the lens.

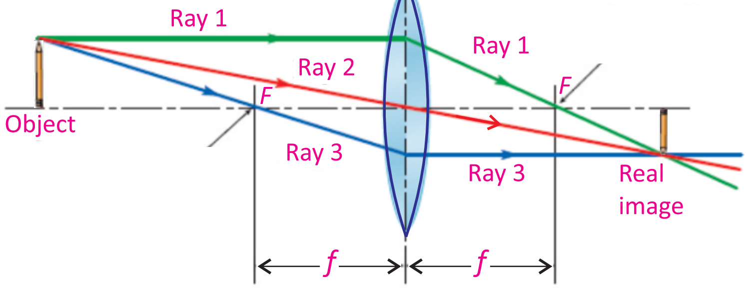


Fig. 12.23: Convex Lens

The ray diagram for concave lens is shown in Fig.12.24.

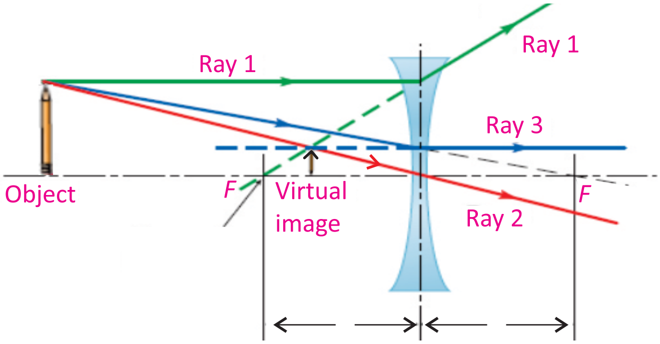
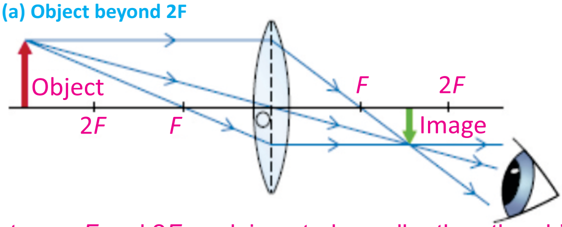


Fig. 12.24: Concave Lens

Image Formation in Convex Lens

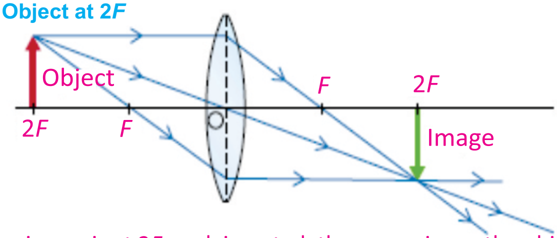
In class VIII, we have learnt image formation by lenses. Let us briefly revise image formation by convex lens (Fig.12.25).

(a) Object beyond 2F



The image is between *F* and 2*F*, real, inverted, smaller than the object.

(b) Object at 2*F*

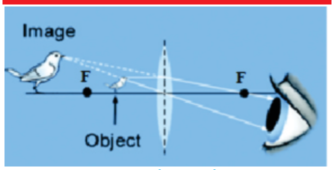


The image is at 2*F*, real, inverted, the same size as the object.

For your information

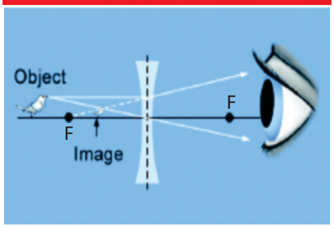
You can compare lenses simply by looking at them.
A lens with a long focal length is thin; its surfaces are not very strongly curved.
A lens with a short focal length is fatter; its surfaces are more strongly curved.

Physics insight



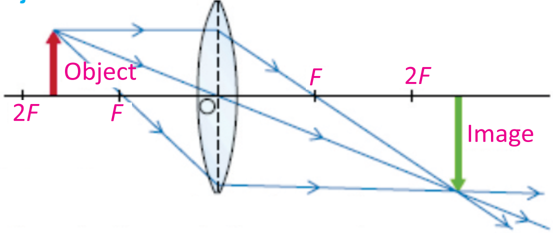
A converging lens becomes a magnifying glass when an object is located inside the lens's focal length.

Physics insight



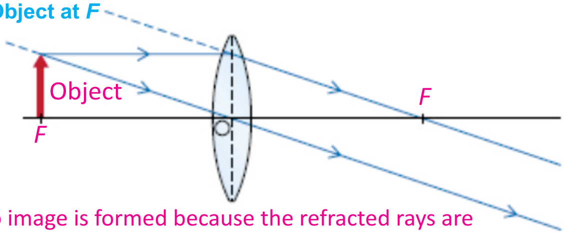
A diverging lens always has the same ray diagram, which forms a smaller image.

(c) Object between *F* and 2*F*



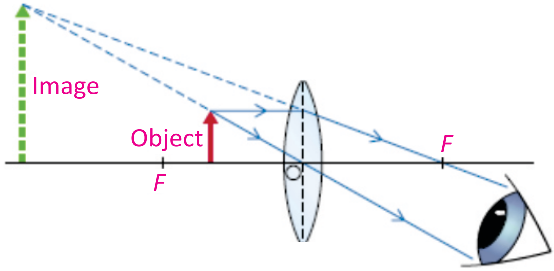
The image is beyond 2*F*, real, inverted, larger than the object.

(d) Object at *F*



No image is formed because the refracted rays are parallel and never meet.

(e) Object between lens and *F*



The image is behind the object, virtual, erect, larger than the object.

Fig. 12.25

> **Approximations**
>
> The thin lens formula assumes the lenses have no thickness. This is a good assumption when objects and images are far away compared with the thickness of a lens.

12.10 IMAGE LOCATION BY LENS EQUATION

In Fig.12.26, let an object OP is placed in front of a convex lens at a distance *p*. A ray PR parallel to the principal axis after refraction passes through focus *F*. Another ray PC meets the first ray at point P' after passing through the optical centre C. If this process is repeated for the other points of the object, a real and inverted image O'P' is formed at a distance *q* from the lens.

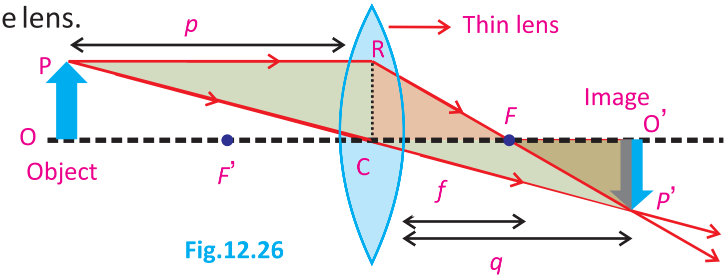


Fig.12.26

> **For your information**
>
> The study of light behaviour is called optics. The branch of optics that focuses on the creation of images is called geometrical optics, because it is based on relationships between angles and lines that describe light rays. With a few rules from geometry, we can explain how images are formed by devices like lenses, mirrors, cameras, telescopes, and microscopes. Optics also includes the study of the eye itself because the human eye forms an image with a lens.

What is the size of image formed in a lens for particular distance of object from the lens? What is the nature of image, i.e., whether image is real or imaginary, erect or inverted? Lens formula is a tool that we use to answer all such questions. We define lens formula as,

The relation between the object and image distance from the lens in terms of the focal length of the lens is called lens formula.

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \qquad \text{.........} \quad (12.4)$$

Equation (12.4) is valid for both concave and convex lenses. However, following sign conventions should be followed while using this equation to solve problems related to lenses.

Sign Conventions for Lenses

Focal length:

- f is positive for a converging lens
- f is negative for a diverging lens.

Object Distance:

- p is positive, if the object is towards the left side of the lens. It is called a real object.
- p is negative, if the object is on the right side of the lens. It is called virtual object.

Image Distance:

- q is positive for a real image made on the right side of the lens by real object.
- q is negative for a virtual image made on the left side on the lens by real object.

Example 12.5: A person 1.7 m tall is standing 2.5 m in front of a camera. The camera uses a convex lens whose focal length is 0.05 m. Find the image distance (the distance between the lens and the film) and determine whether the image is real or virtual.

Solution: To find the image distance q, we use the thin lens equation with $p = 2.5$ m and $f = 0.05$ m.

Uses of lenses


Spectacles


Magnifying Glass


Microscope


Slide projector


Binoculars


Camera

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p}$$

$$\frac{1}{q} = \frac{1}{0.05\text{ m}} - \frac{1}{2.5\text{ m}}$$

$$\frac{1}{q} = 19.6\text{ m}^{-1}$$

or $\quad q = 0.05$ m

Since the image distance is positive, so a real image is formed on the film at the focal point of the lens.

Example 12.6: A concave lens has focal length of 15 cm. At what distance should the object from the lens be placed so that it forms an image at 10 cm from the lens? Also find the magnification of the lens.

Solution: A concave lens always forms a virtual, erect image on the same side of the object. Given that, $q = -10$ cm

$f = -15$ cm, $p = ?$

Using the lens formula: $$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\frac{1}{p} = -\frac{1}{q} + \frac{1}{f}$$

$$= -\frac{1}{(-10\text{ cm})} + \frac{1}{(-15\text{ cm})}$$

$$= \frac{1}{10\text{ cm}} - \frac{1}{15\text{ cm}}$$

$$\frac{1}{p} = \frac{3\text{ cm} - 2\text{ cm}}{30\text{ cm}^2}$$

$$\frac{1}{p} = \frac{1}{30\text{ cm}}$$

$$p = 30\text{ cm}$$

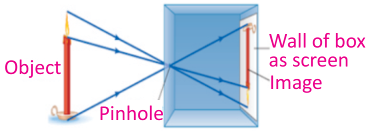
Thus, the object distance is 30 cm, on the left side from the concave lens.

Magnification of the lens is $m = \dfrac{q}{p} = \dfrac{-10\text{ cm}}{30\text{ cm}} = \dfrac{1}{3}$

(Ignore nagetive sign)

The image is reduced to one-third in size than the object.

A camera without lens!



Even simpler than a camera with one lens is a pinhole camera. To make a pinhole camera, a tiny pinhole is made in one side of a box. An inverted, real image is formed on the opposite side of the box.

12.11 APPLICATIONS OF LENSES

Now we discuss applications of lenses in some optical devices such as camera, slide projector and photograph enlarger.

1. CAMERA

A simple camera consists of a light-proof box with a converging lens in front and a light sensitive plate or film at the back. The lens focuses images to be photographed onto the film. In simple lens camera, the distance between lens and film is fixed which is equal to the focal length of the lens. In camera, object is placed beyond 2*F*. A real, inverted and diminished image is formed in this way as shown in Fig.12.27.

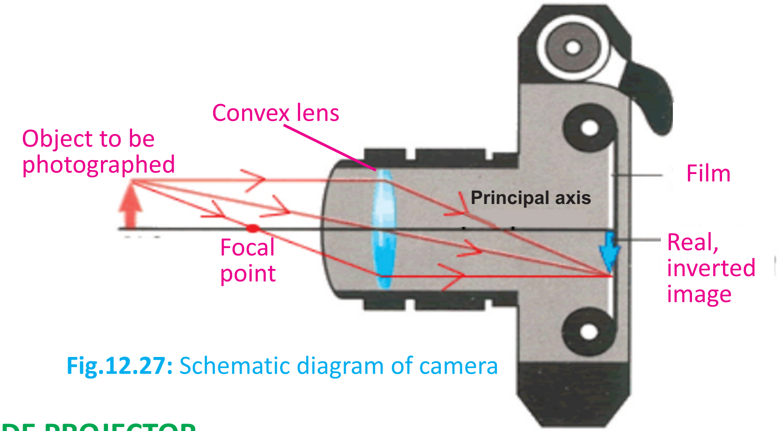


Fig.12.27: Schematic diagram of camera

2. SLIDE PROJECTOR

Fig.12.28 shows how a slide or movie projector works. The light source is placed at the centre of curvature of a converging or concave mirror. The concave mirror is used to reflect light back in fairly parallel rays. The condenser is made up of 2 converging lenses that refract the light so all parts of the slide are illuminated with parallel rays.

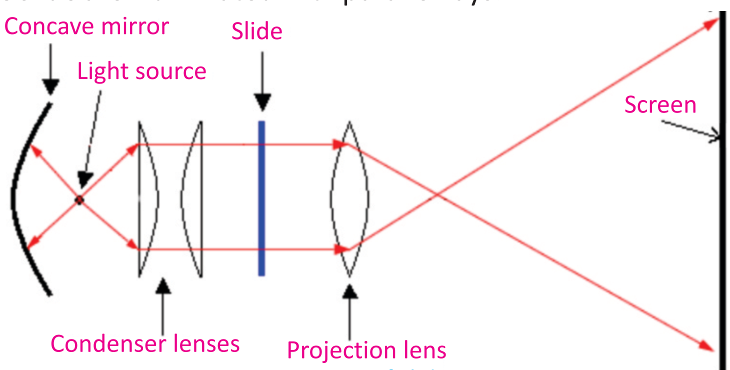


Fig.12.28: Diagram of slide projector

Self Assessment

Where a pen is placed in front of a convex lens if the image is equal to the size of the pen? What will be the power of the lens in dioptres?

The projection or converging lens provides a real, large and inverted image. It must be real to be projected on a screen. The slide (object) must be placed between F and 2F of projection lens so as to produce a real, large, and inverted image. Because the image is inverted, the slide must be placed upside down and laterally inverted so we can see the image properly.

3. PHOTOGRAPH ENLARGER

In the case of photograph enlarger object is placed at distance of more than *F* but less than 2*F*. In this way, we get a real, inverted and enlarged image as shown in Fig. 12.29. The working principle of photograph enlarger is basically the same as that of a slide projector. It uses a convex lens to produce a real, magnified and inverted image of the film on photographic paper.

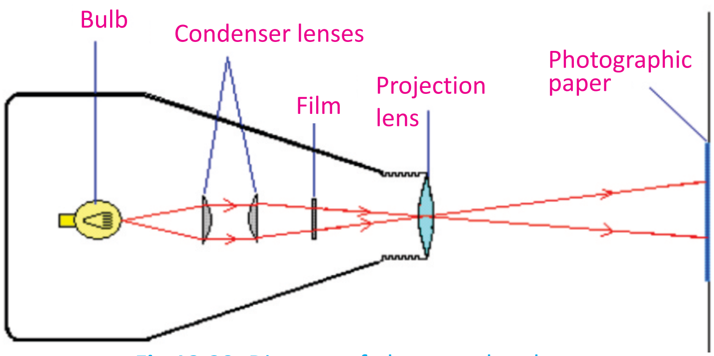


Fig.12.29: Diagram of photograph enlarger

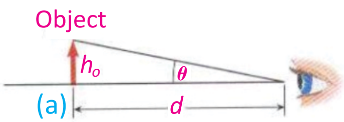


Fig.12.30

12.12 SIMPLE MICROSCOPE

A magnifying glass is a convex lens which is used to produce magnified images of small objects. Hence, it is also called simple microscope. The object is placed nearer to the lens than the principal focus such that an upright, virtual and magnified image is seen clearly at 25cm from the normal eye.

Magnifying Power

Let θ be the angle subtended at the eye by a small object when it is placed at near point of the eye(Fig.12.30-a).

If the object is now moved nearer to the eye(Fig.12.30-b), the angle on the eye will increase and becomes θ', but the eye will not be able to see it clearly. In order to see the object clearly,

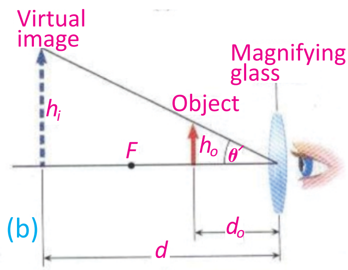


Fig.12.30: Image formation in magnifying glass

we put a convex lens between the object and the eye, so that the lens makes a large virtual image of the object at near point of the eye. In this way, the object appears magnified. The magnifying power in this case will be:

$$M = \frac{\theta'}{\theta}$$

It can be shown that the magnifying power is given by the relation:

$$M = \frac{\theta'}{\theta} = 1 + \frac{d}{f}$$

where f is the focal length of lens and d is near point of eye. It is clear from this relation that a lens of shorter focal length will have greater magnifying power.

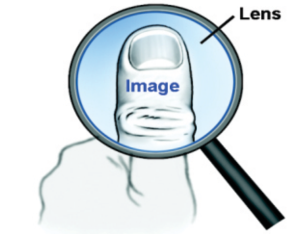
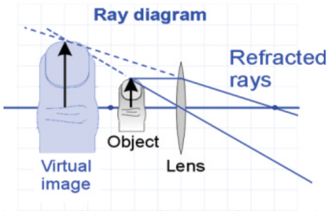


Image in a magnifying glass



Magnifying glass is a lens that forms a virtual image that is larger than object and appears behind the lens.

Resolving Power

The resolving power of an instrument is its ability to distinguish between two closely placed objects or point sources.

In order to see objects that are close together, we use an instrument of high resolving power. For example, we use high resolving power microscope to see tiny organisms and telescope to view distant stars.

12.13 COMPOUND MICROSCOPE

Compound microscope has two converging lenses, the objective and the eyepiece and is used to investigate structure of small objects (Fig.12.31). Following are some features of compound microscope:

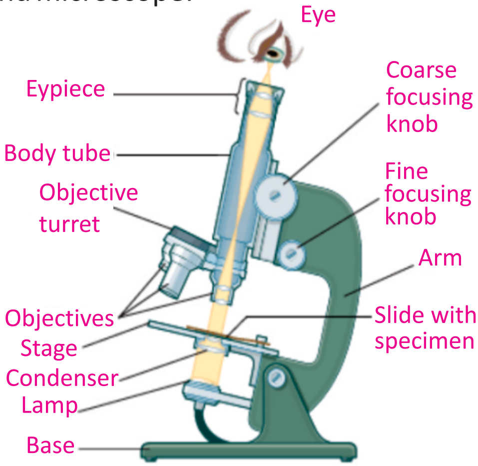


Fig.12.31: Compound microscope

- It gives greater magnification than a single lens.
- The objective lens has a short focal length, $f_o < 1$ cm.
- The eyepiece has a focal length, f_e of a few cm.

Magnification of the Compound Microscope

Magnification can be determined through the ray diagram as shown in Fig. 12.32. Objective forms a small image I_1 inside the focal point of eyepiece. This image acts as an object for the eyepiece and the final larger image I_2 is formed outside the focal point of the objective.

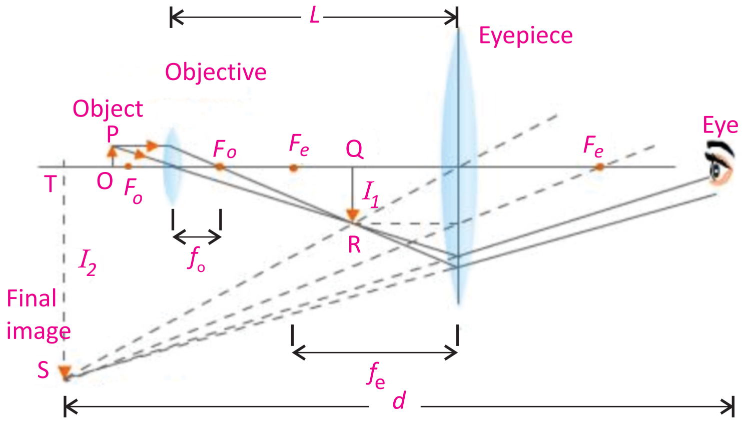


Fig. 12.32: Ray diagram for compound microscope

The magnification of a compound microscope is given by

$$M = \frac{L}{f_o}\left(1 + \frac{d}{f_e}\right)$$

where L is the length of a compound microscope which is equal to the distance between objective and eye piece, d is distance of final image from eye, f_o and f_e are the focal lengths of objective and eye piece respectively.

Uses of Compound Microscope

A compound microscope is used to study bacteria and other micro objects. It is also used for research in several fields of sciences like, Microbiology, Botany, Geology, and Genetics.

12.14 TELESCOPE

Telescope is an optical instrument which is used to observe distant objects using lenses or mirrors. A telescope that uses

Compound microscops

Objective lens has smaller focal length, than the eyepiece.
Distance between the objective lens and the eyepiece is greater than f_0+f_e. It is used to see very small objects.

Astronomical telescope

Objective lens has larger focal length than the eyepiece.
Distance between the objective lens and the eyepiece is equal to f_0+f_e.
It is used to see distant astronomical objects.

two converging lenses is called *refracting telescope* (Fig.12.33). In refracting telescope, an objective lens forms a real image of the distant object, while an eyepiece forms a virtual image that is viewed by the eye.

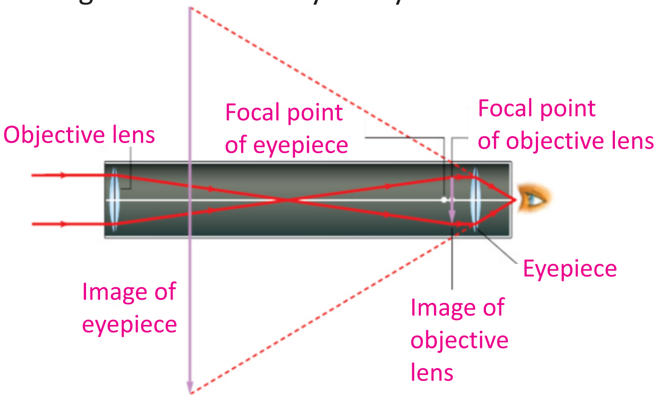


Fig. 12.33: An astronomical refracting telescope creates a virtual image that is inverted compared to the object.

WORKING OF REFRACTING TELESCOPE

The ray diagram of refracting telescope is shown in Fig.12.34. When parallel rays from a point on a distant object pass through objective lens, a real image I_1 is formed at the focus F_o of the objective lens. This image acts as an object for the eyepiece. A large virtual image I_2 of I_1 is formed by the eyepiece at a large distance from the objective lens. This virtual image makes an angle θ at the eyepiece.

Magnification of Telescope

Magnification of a refracting telescope can be determined through the ray diagram of Fig. 12.34 and is given by $M = \frac{f}{f_e}$

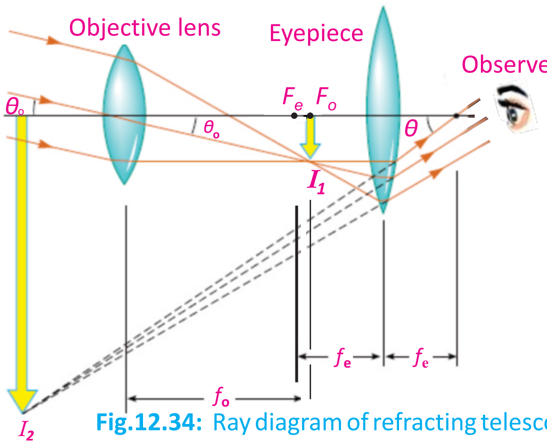


Fig.12.34: Ray diagram of refracting telescope

For your information

Terrestrial telescope is similar to refracting telescope except with an extra lens between objective and eyepiece.

For your information

The magnification of a combination of lenses is equal to the product of the magnifications of each lens.

For your information

A telescope cannot make stars look bigger, because they are too far away. But there is something important the telescope can do – it makes stars look brighter. Dim stars look bright, and stars that are too faint to see come into view. Without a telescope, we can see up to 3000 individual stars in the night sky; a small telescope can increase this by a factor of at least 10. So a telescope is better than the naked eye for seeing dim stars. The reason is that the telescope gathers more light than the eye.

12.15 THE HUMAN EYE

The image formation in human eye is shown in Fig.12.35. Human eye acts like a camera. In place of the film, the retina records the picture. The eye has a refracting system containing a converging lens. The lens forms an image on the retina which is a light sensitive layer at the back of the eye. In the camera, the distance of lens from film is adjusted for proper focus but in the eye, the lens changes focal length. Light enters the eye through a transparent membrane called the cornea. The iris is the coloured portion of the eye and controls the amount of light reaching the retina. It has an opening at its centre called the *pupil.* The iris controls the size of the pupil. In bright light, iris contracts the size of the pupil while in dim light pupil is enlarged. The lens of the eye is flexible and accommodates objects over a wide range of distances.

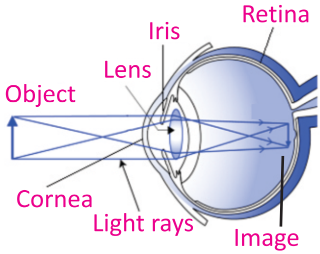


Fig.12.35: Image formation in human eye

Accommodation

The camera focuses the image of an object at a given distance from it by moving the lens towards or away from the film. The eye has different adjusting mechanism for focusing the image of an object onto the retina. Its ciliary muscles control the curvature and thus the focal length of the lens, and allow objects at various distances to be seen.

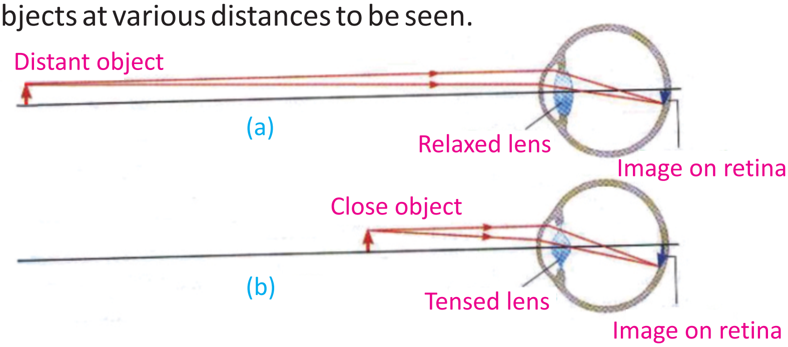
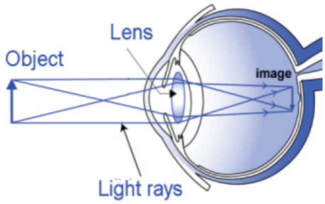


Fig.12.36: Human eye accommodation

If an object is far away from the eye, the deviation of light through the lens must be less. To do this, the ciliary muscles relax and decrease the curvature of the lens, thereby, increasing the focal length. The rays are thus focused onto the retina producing a sharp image of the distant object (Fig.12.36-a).

For your information

The eye



We see because the eye forms images on the retina at the back of the eyeball.

Quick Quiz

How the size of the pupil of our eye will change:

(a) in dim light?

(b) in bright light?

If an object is close to the eye, the ciliary muscles increase curvature of the lens, thereby, shortening the focal length. The divergent rays from the nearer object are thus bent more so as to come to a focus on the retina (Fig.12.36-b).

The variation of focal length of eye lens to form a sharp image on retina is called accommodation.

It is large in young people while it goes on decreasing with age. Defects in accommodation may be corrected by using different type of lenses in eyeglasses. In the following sections, we will describe defect of vision and their remedies.

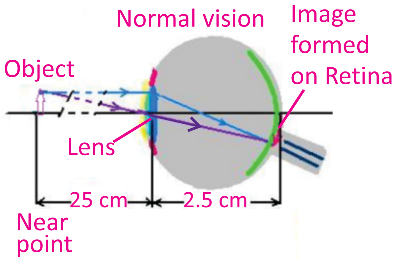


Fig.12.37: Image formation in human eye when object is placed at near point.

Near Point and Far Point

When we hold a book too close, the print is blurred because the lens cannot adjust enough to bring the book into focus.

The near point of the eye is the minimum distance of an object from the eye at which it produces a sharp image on the retina.

This distance is also called the least distance of distinct vision (Fig.12.37). An object closer to the eye than the near point appears blurred. For people in their early twenties with normal vision, the near point is located about 25 cm from the eye. It increases to about 50 cm at the age 40 years and to roughly 500 cm at the of age 60 years.

The far point of the eye is the maximum distance of a distant object from the eye on which the fully relaxed eye can focus.

A person with normal eyesight can see objects very far away, such as the planets and stars, and thus has a far point located at infinity. Majority of people not have "normal eyes" in this sense!

Do you know?

Contact lenses produce the same results as eyeglasses do. These small, thin lenses are placed directly on the corneas. A thin layer of tears between the cornea and lens keeps the lens in place. Most of the refraction occurs at the air-lens surface, where the difference in indices of refraction is greatest.

12.16 DEFECTS OF VISION

The inability of the eye to see the image of objects clearly is called defect of vision.

The defects of vision arise when the eye lens is unable to accommodate effectively. The images formed are therefore blurred.

Nearsightedness (myopia)

Some people cannot see distant objects clearly without the aid of spectacles. This defect of vision is known as short sight or nearsightedness and it may be due to the eyeball being too

long. Light rays from a distant object are focused in front of the retina and a blurred image is produced (Fig.12.38-a).

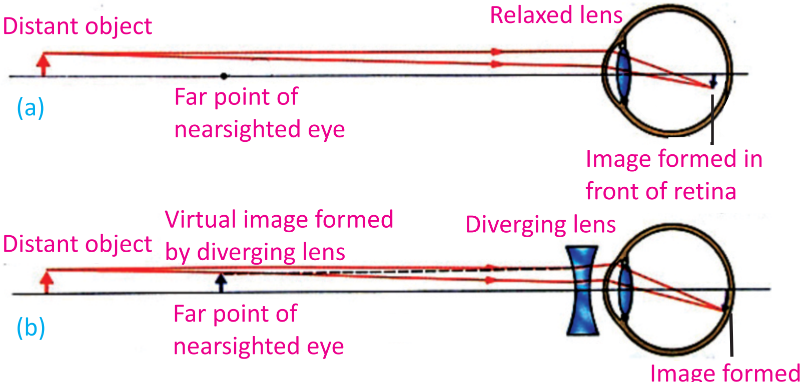


Fig. 12.38: Correction of near sightedness

The nearsighted eye can be corrected with glass or contact lenses that use diverging lenses. Light rays from the distant objects are now diverged by this lens before entering the eye. To the observer, these light rays appear to come from far point and are therefore focused on the retina, thus forming a sharp image (Fig.12.38-b).

Farsightedness (hypermetropia)

The disability of the eye to form distinct images of nearby objects on its retina is known as farsightedness.

When a farsighted eye tries to focus on a book held closer than the near point, it shortens its focal length as much as it can. However, even at its shortest, the focal length is longer than it should be. Therefore, the light rays from the book would form a blurred image behind the retina (Fig.12.39-a).

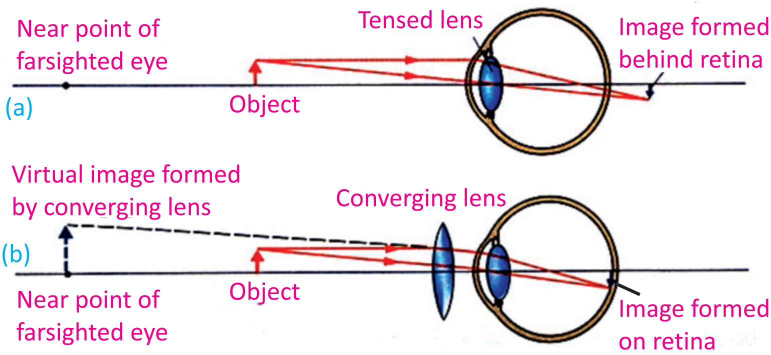


Fig. 12.39: Correction of farsightedness

Interesting information

Some animals like fish has the ability to move their eye lenses forward or backward and hence, are able to see clearly objects around them.

For your information

A thin film can be placed on the lenses of eyeglasses to keep them from reflecting wavelengths of light that are highly visible to the human eye. This prevents the glare of reflected light.

This defect can be corrected with the aid of a suitable converging lens. The lens refracts the light rays and they converge to form an image on the retina. To an observer, these rays appear to come from near point to form a sharp virtual image on the retina (Fig.12.39-b).

SUMMARY

- When light travelling in a certain medium falls on the surface of another medium, a part of it turns back in the same medium. This is called reflection of light. There are two laws of reflection:
  i. The incident ray, the reflected ray, and the normal all lie in the same plane.
  ii. The angle of incidence is equal to the angle of reflection (i.e., i = r).
- Like plane surfaces, spherical surfaces also reflect light satisfying the two laws of reflection.
- In mirrors, image formation takes place through reflection of light while in lenses image is formed through refraction of light.
- The equation relating the distance of the object p from the mirror/lens, distance of the image q and the focal length f of the mirror/lens is called mirror/lens formula, given by $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$
- Magnification of a spherical mirror or thin lens is defined as "the ratio of the image height to the object height." i.e., Magnification $m = \frac{\text{Image height}}{\text{Object height}} = \frac{h_i}{h_o}$
- Power of a lens is defined as "the reciprocal of its focal length in metres". Thus Power of a lens = P = 1 / focal length in metres. The SI unit of power of a lens is "Dioptre", denoted by a symbol D. If f is expressed in metres so that 1 D = 1 m^{-1}. Thus, 1 Dioptre is the power of a lens whose focal length is 1 metre.
- The refractive index 'n' of a material is the ratio of the speed of light 'c' in air to the speed of light 'v' in the material, thus

$$n = \frac{\text{Speed of light in air}}{\text{Speed of light in medium}} = \frac{c}{v}$$

- The bending of light from its straight path as it passes from one medium into another is called *refraction*.
- Refraction of light takes place under two laws called laws of refraction. These are stated as:
  i. *The incident ray, the refracted ray, and the normal at the point of incidence all lie in the same plane.*

ii. *The ratio of the sine of the angle of incidence 'i' to the sine of the angle of refraction 'r' is always equal to a constant i.e.,* $\frac{\sin i}{\sin r}$ *= constant.*

where the ratio $\frac{\sin i}{\sin r}$ is equal to the refractive index of the second medium with respect to the first medium.

$$\text{i.e.,}\quad \frac{\sin i}{\sin r} = n$$

This is also called Snell's law.

- The angle of incidence for which the angle of refraction becomes 90° is called critical angle. When the angle of incidence becomes larger than the critical angle, no refraction occurs. The entire light is reflected back into the denser medium. This is known as total internal reflection of light.
- A simple microscope, also known as a magnifying glass, is a convex lens which is used to produce magnified images of small objects.
- A compound microscope is used to investigate structure of small objects and has two converging lens, the objective and the eyepiece.
- Telescope is an optical instrument which is used to observe distant objects using lenses or mirrors. A telescope that uses two converging lenses is called refracting telescope. A telescope in which the objective lens is replaced by a concave mirror is called *reflecting power telescope*.
- The magnifying power is defined as "the ratio of the angle subtended by the image as seen through the optical device to that subtended by the object at the unaided eye".
- The resolving power of an instrument is its ability to distinguish between two closely placed objects.
- The ability of the eye to change the focal length of its lens so as to form a clear image of an object on its retina is called its power of accommodation.
- The disability of the eye to form distinct images of distant objects on its retina is known as nearsightedness**.** The nearsighted eye can be corrected with glass or contact lenses that use *diverging* lenses. Light rays from the distant objects will diverge by this lens before entering the eye.
- The disability of the eye to form distinct images of nearby objects on its retina is known as *farsightedness.* This defects can be corrected with the aid of a suitable converging lens. The lens refracts the light rays more towards the principal axis before they enter the eye.

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the given choices:

i. Which of the following quantity is not changed during refraction of light?
   (a) its direction (b) its speed
   (c) its frequency (d) its wavelength

ii. A converging mirror with a radius of 20 cm creates a real image 30 cm from the mirror. What is the object distance?
   (a) -5.0 cm (b) -7.5 cm
   (c) -15 cm (d) -20 cm

iii. An object is placed at the centre of curvature of a concave mirror. The image produced by the mirror is located
   (a) out beyond the centre of curvature.
   (b) at the centre of curvature.
   (c) between the centre of curvature and the focal point
   (d) at the focal point

iv. An object is 14 cm in front of a convex mirror. The image is 5.8 cm behind the mirror. What is the focal length of the mirror?
   (a) -4.1 cm (b) -8.2 cm
   (c) -9.9 cm (d) -20 cm

v. The index of refraction depends on
   (a) the focal length (b) the speed of light
   (c) the image distance (d) the object distance

vi. Which type of image is formed by a concave lens on a screen?
   (a) inverted and real (b) inverted and virtual
   (c) upright and real (d) upright and virtual

vii. Which type of image is produced by the converging lens of human eye if it views a distant object?
   (a) real, erect, same size (b) real, inverted, diminished
   (c) virtual, erect, diminished (d) virtual, inverted, magnified

viii. Image formed by a camera is
   (a) real, inverted, and diminished
   (b) virtual, upright and diminished
   (c) virtual, upright and magnified
   (d) real, inverted and magnified

ix. If a ray of light in glass is incident on an air surface at an angle greater than the critical angle, the ray will
   (a) refract only

(b) reflect only
(c) partially refract and partially reflect
(d) diffract only

x. The critical angle for a beam of light passing from water into air is 48.8 degrees. This means that all light rays with an angle of incidence greater than this angle will be
(a) absorbed
(b) totally reflected
(c) partially reflected and partially transmitted
(d) totally transmitted

REVIEW QUESTIONS

12.1. What do you understand by reflection of light? Draw a diagram to illustrate reflection at a plane surface.

12.2. Describe the following terms used in reflection:
(i) normal (ii) angle of incidence (iii) angle of reflection

12.3. State laws of reflection. Describe how they can be verified graphically.

12.4. Define refraction of light. Describe the passage of light through parallel-sided transparent material.

12.5. Define the following terms used in refraction:
(i) angle of incidence (ii) angle of refraction

12.6. What is meant by refractive index of a material? How would you determine the refractive index of a rectangular glass slab?

12.7. State the laws of refraction of light and show how they may be verified using rectangular glass slab and pins.

12.8. What is meant by the term total internal reflection?

12.9. State the conditions for total internal reflection.

12.10. What is critical angle? Derive a relationship between the critical angle and the refractive index of a substance.

12.11. What are optical fibres? Describe how total internal reflection is used in light propagating through optical fibres.

12.12. Define the following terms applied to a lens:
(i) principal axis (ii) optical centre (iii) focal length

12.13. What is meant by the principal focus of a (a) convex lens (b) concave lens? Illustrate your answer with ray diagrams.

12.14. Describe how light is refracted through convex lens.

12.15. With the help of a ray diagram, how you can show the use of thin converging lens as a magnifying glass.

12.16. A coin is placed at a focal point of a converging lens. Is an image formed? What is its nature?

12.17. What are the differences between real and virtual images?

12.18. How does a converging lens form a virtual image of a real object? How does a diverging lens can form a real image of a real object?

12.19. Define power of a lens and its units.

12.20. Describe the passage of light through a glass prism and measure the angle of deviation.

12.21. Define the terms resolving power and magnifying power.

12.22. Draw the ray diagrams of
(i) simple microscope (ii) compound microscope (iii) refracting telescope

12.23. Mention the magnifying powers of the following optical instruments:
(i) simple microscope (ii) compound microscope (iii) refracting telescope

12.24. Draw ray diagrams to show the formation of images in the normal human eye.

12.25. What is meant by the terms nearsightedness and farsightedness? How can these defects be corrected?

CONCEPTUAL QUESTIONS

12.1. A man raises his left hand in a plane mirror, the image facing him is raising his right hand. Explain why.

12.2. In your own words, explain why light waves are refracted at a boundary between two materials.

12.3. Explain why a fish under water appears to be at a different depth below the surface than it actually is. Does it appear deeper or shallower?

12.4. Why or why not concave mirrors are suitable for makeup?

12.5. Why is the driver's side mirror in many cars convex rather than plane or concave?

12.6. When an optician's testing room is small, he uses a mirror to help him test the eyesight of his patients. Explain why.

12.7. How does the thickness of a lens affect its focal length?

12.8. Under what conditions will a converging lens form a virtual image?

12.9. Under what conditions will a converging lens form a real image that is the same size as the object?

12.10. Why do we use refracting telescope with large objective lens of large focal length?

NUMERICAL PROBLEMS

12.1. An object 10.0 cm in front of a convex mirror forms an image 5.0 cm behind the mirror. What is the focal length of the mirror? **Ans. (-**

10 cm)

12.2. An object 30 cm tall is located 10.5 cm from a concave mirror with focal length 16 cm. (a) Where is the image located? (b) How high is it?

Ans. [(a) 30.54 cm (b) 87.26 cm]

12.3. An object and its image in a concave mirror are of the same height, yet inverted, when the object is 20 cm from the mirror. What is the focal length of the mirror?

Ans. (10 cm)

12.4. Find the focal length of a mirror that forms an image 5.66 cm behind the mirror of an object placed at 34.4 cm in front of the mirror. Is the mirror concave or convex?

Ans. (-6.77 cm, Convex mirror)

12.5. An image of a statue appears to be 11.5 cm behind a concave mirror with focal length 13.5 cm. Find the distance from the statue to the mirror. **Ans. (77.62 cm)**

12.6. An image is produced by a concave mirror of focal length 8.7 cm. The object is 13.2 cm tall and at a distance 19.3 cm from the mirror. (a) Find the location and height of the image. (b) Find the height of the image produced by the mirror if the object is twice as far from the mirror.

Ans. [(a) 15.84 cm, 10.83 cm (b) 5.42 cm]

12.7. Nabeela uses a concave mirror when applying makeup. The mirror has a radius of curvature of 38 cm. (a) What is the focal length of the mirror? (b) Nabeela is located 50 cm from the mirror. Where will her image appear? (c) Will the image be upright or inverted? **Ans. [(a) 19 cm, (b) 30.64 cm, (c) upright]**

12.8. An object 4 cm high is placed at a distance of 12 cm from a convex lens of focal length 8 cm. Calculate the position and size of the image. Also state the nature of the image.

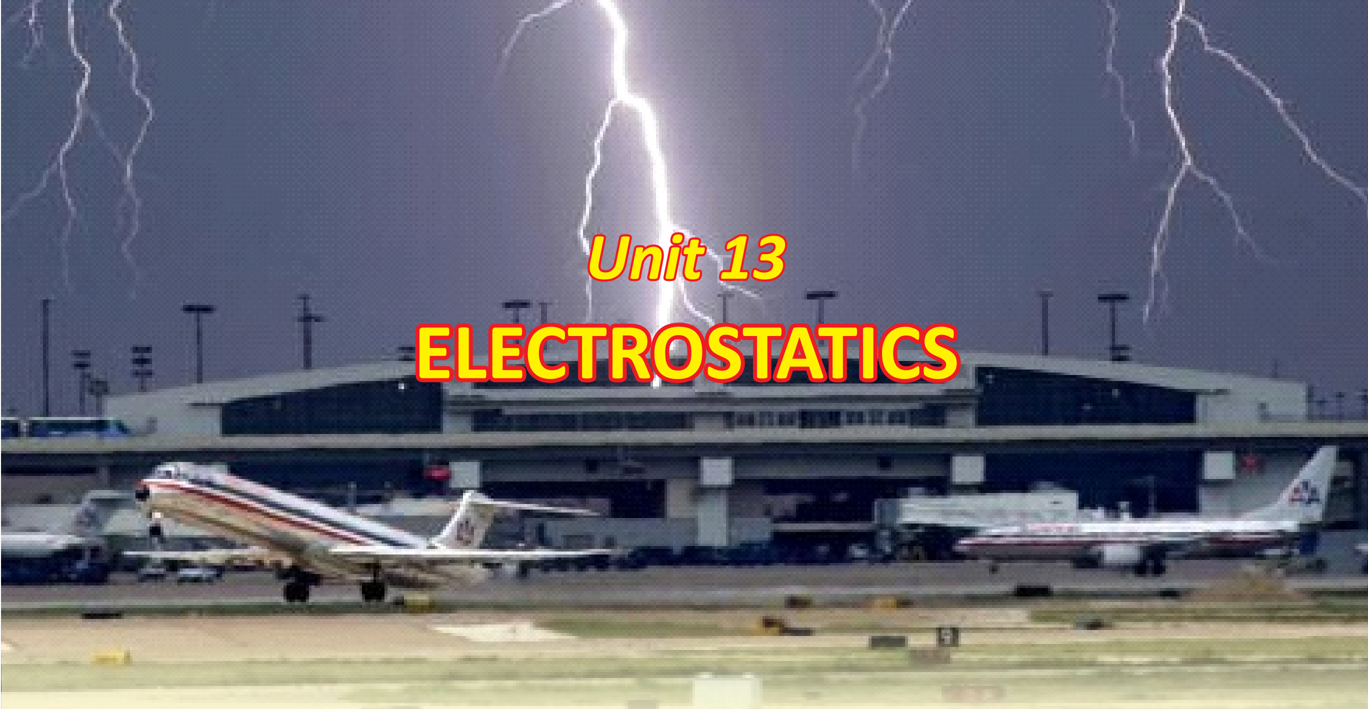
Ans. (24 cm, 8 cm, image is real, inverted and magnified)

12.9. An object 10 cm high is placed at a distance of 20 cm from a concave lens of focal length 15 cm. Calculate the position and size of the image. Also, state the nature of the image. **Ans. (-8.57 cm, 4.28 cm, image is virtual, erect and diminished)**

12.10. A convex lens of focal length 6 cm is to be used to form a virtual image three times the size of the object. Where must the lens be placed? **Ans. (4 cm)**

12.11. A ray of light from air is incident on a liquid surface at an angle of incidence 35°. Calculate the angle of refraction if the refractive index of the liquid is 1.25. Also calculate the critical angle between the liquid air inter-face. **Ans. (27.31°, 53.13°)**

12.12. The power of a convex lens is 5 D. At what distance the object should be placed from the lens so that its real and 2 times larger image is formed. **Ans. (30 cm)**



Unit 13
ELECTROSTATICS

After studying this unit, students will be able to:

- describe simple experiments to show the production and detection of electric charge.
- describe experiments to show electrostatic charging by induction.
- state that there are positive and negative charges.
- describe the construction and working principle of electroscope.
- state and explain Coulomb’s law.
- solve problems on electrostatic charges by using Coulomb’s law.
- define electric field and electric field intensity.
- sketch the electric field lines for an isolated +ve and –ve point charges.
- describe the concept of electrostatic potential.
- define the unit “volt”.
- describe potential difference as energy transfer per unit charge.
- describe one situation in which static electricity is dangerous and the precautions taken to ensure that static electricity is discharged safely.
- describe that the capacitor is charge storing device.
- define capacitance and its unit.
- derive the formula for the effective capacitance of a number of capacitors connected in series and in parallel.
- apply the formula for the effective capacitance of a number of capacitors connected in series and in parallel to solve related problems.

Science, Technology and Society Connections

The students will be able to:

- describe the use of electrostatic charging (e.g. spraying of paint and dust extraction).
- list the use of capacitors in various electrical appliances.

In this chapter, we will describe different properties of static charges, such as electric force, electric field and electric potential etc. We will also discuss some uses and safety measures of static electricity. The study of charges at rest is called electrostatics or static electricity.

Fig.13.1: Comb rubbed with hair attracts small pieces of paper

13.1 PRODUCTION OF ELECTRIC CHARGES

If we run a plastic comb through our hair and then bring it near small pieces of paper, the comb attracts them (Fig.13.1). Similarly, amber when rubbed with silk, attracts the small pieces of paper. This property of attraction or repulsion between substances is due to the electric charges they acquire during rubbing.

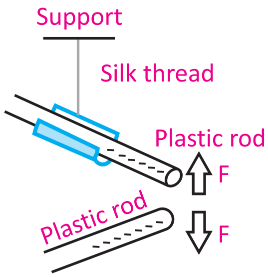


Fig.13.2: Two plastic rods rubbed with fur repel each other

We can produce electric charge by rubbing a neutral body with another neutral body. The following activities show that we can produce two types of electric charges through the process of rubbing.

Activity 13.1. Take a plastic rod. Rub it with fur and suspend it horizontally by a silk thread (Fig. 13.2). Now take another plastic rod and rub it with fur and bring near to the suspended rod. We will observe that both the rods will repel each other. It means during the rubbing both the rods were charged.

Activity 13.2. Now take a glass rod and rub it with silk and suspend it horizontally. When we bring the plastic rod rubbed with fur near to the suspended glass rod, we observe that both the rods attract each other (Fig. 13.3).

In the first activity, both rods are of plastic and both of them have been rubbed with fur. Therefore, we assume that charge on both rods would be of the same kind.

In the second activity, rods are unlike and their attraction implies that charges on two rods are not of the same kind but of opposite nature.

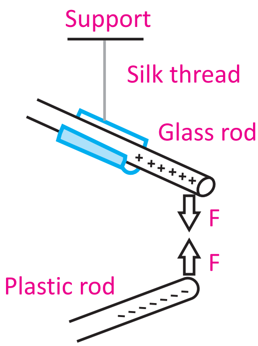


Fig.13.3: Plastic rod rubbed with fur and glass rod rubbed with silk attract each other

These opposite charges are conventionally called positive charge and negative charge. During the process of rubbing negative charge is transferred from one object to another object.

From these activities, we conclude that:

1. Charge is a basic property of a material body due to which it attracts or repels another object.
2. Friction produces two different types of charge on different materials (such as glass and plastic).
3. Like charges always repel each other.
4. Unlike charges always attract each other.
5. Repulsion is the sure test of charge on a body.

For your information

In the list given below, different materials have been arranged in such a way that if any of the two materials are rubbed together, the material occurring first in the list would have positive charge and that occurring next would have negative charge. For example, among cat's skin and lead, skin has positive charge whereas lead has negative charge.

1. Asbestos
2. Glass
3. Mica
4. Woollen cloth
5. Cat's skin
6. Lead
7. Silky cloth
8. Aluminium
9. Cotton cloth
10. Wood
11. Copper
12. Rubber
13. Plastic

Self Assessment

1. Do you think amount of positive charge on the glass rod after rubbing it with silk cloth will be equal to the amount of negative charge on the silk? Explain.
2. What would happen if a neutral glass rod is brought near a positively charged glass rod?

13.2 ELECTROSTATIC INDUCTION

Activity 13.3. If we bring charged plastic rod near suspended neutral aluminium rod, both rods attract each other as shown in Fig. 13.4.

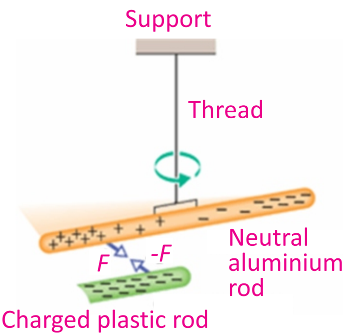


Fig. 13.4: Charged plastic rod attracts neutral aluminium rod.

This attraction between the charged and uncharged rods shows as if both rods have unlike charges. But this is not true. Charged plastic rod produces displacement of positive and negative charges on the neutral aluminium rod which is the cause of attraction between them. But total charge on aluminium rod is still zero. It implies that attraction is not the sure test of charge on a body.

The above activity shows a phenomenon that is called electrostatic induction as explained below.

Activity 13.4. Bring two metal spheres A and B and fix them on

insulated stands, such that they touch each other as shown in Fig.13.5-a. Now bring a positively charged rod near sphere A as shown in Fig. 13.5-b. Rod will attract negative charge towards it and repel positive charge away from it. Negative charge will appear on the left surface of the sphere A which is close to the rod. While positive charge will appear on the right surface of the sphere B. Now separate the spheres while the rod is still near the sphere A. Now if you test the two spheres, you will find that the two spheres will be oppositely charged (Fig.13.5-c). After removing the rod, the charges are uniformly distributed over the surfaces of the spheres as shown in Fig.13.5-d.

In this process, an equal and opposite charges appear on each metal sphere. This is called *charging by induction*.

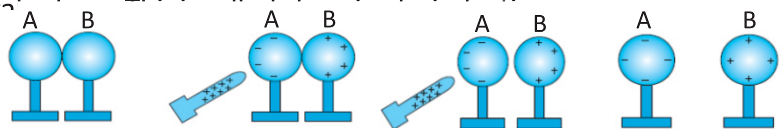
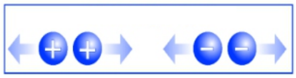
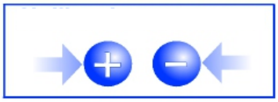


Fig. 13.5: Charging two spheres by electrostatic induction

For your information



Like charges repel



Unlike charges attract

Hence, we define electrostatic induction as:

In the presence of a charged body, an insulated conductor develops positive charge at one end and negative charge at the other end. This process is called the electrostatic induction.

13.3 ELECTROSCOPE

The gold leaf electroscope is a sensitive instrument for detecting charges. It consists of a brass rod with a brass disk at the top and two thin leaves of gold foil hanging at the bottom (Fig. 13.6). The rod passes through an insulator that keeps the rod in place . Charges can move freely from the disk to the leaves through the rod. A thin aluminium foil is attached on the lower portion of the inside of the jar. Usually, the aluminium foil is grounded by connecting a copper wire. This protects the leaves from the external electrical disturbances.

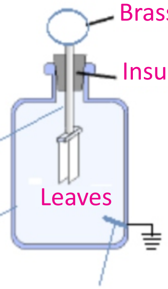


Fig.13.6: Uncharged electroscope

Detecting the Presence of Charge

In order to detect the presence of charge on anybody, bring the body near the disk of an uncharged electroscope. If the body is neutral there will be no deflection of the leaves (Fig.13.7-a). But if the body is positively or negatively charged, the leaves of the electroscope diverge. For example, if the body is negatively charged then due to electrostatic induction, positive charge will appear on the disk while negative charge will appear on the leaves (Fig.13.7-b). The leaves of electroscope repel each other and diverge because each leave gets similar charge. The divergence of leaves will depend on the amount of charge.

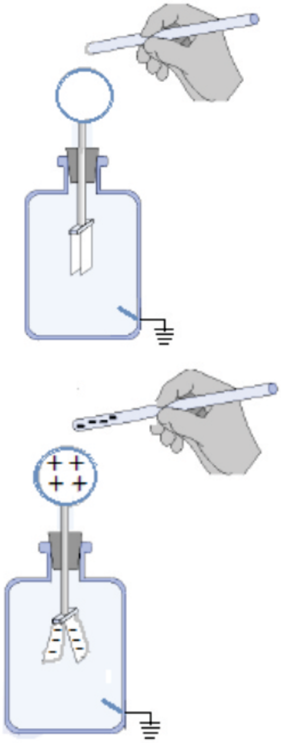

(a)
(b)

Fig. 13.7

Charging the Electroscope by Electrostatic Induction

Electroscope can be charged by the process of electrostatic induction. In order to produce positive charge on the electroscope, bring a negatively charged body near the disk of the electroscope (Fig.13.8-a). Positive charge will appear on the disk of the electroscope while negative charges will shift to the leaves. Now connect the disk of electroscope to the earthed aluminium foil by a conducting wire (Fig. 13.8-b). Charge of the leaves will flow to the Earth through the wire. Now if we first break the Earth connection and then remove the rod, the electroscope will be left with positive charge(Fig.13.8-c).

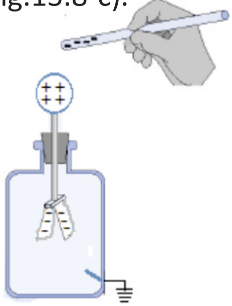


Fig.13.8 (a) Charging the electroscope positively

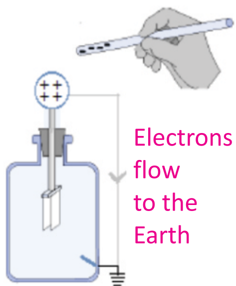


Fig.13.8 (b) Charging the electroscope positively

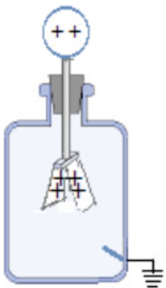


Fig.13.8 (c) Positively charged electroscope

Similarly, electroscope can be charged negatively with the help of a positively charged rod. Can you explain this with the help of a diagram?

Electroscope can also be charged by the process of conduction. Touch a negatively charged rod with the disk of a neutral electroscope. Negative charge from the rod will transfer to the electroscope and will cause its leaves to diverge.

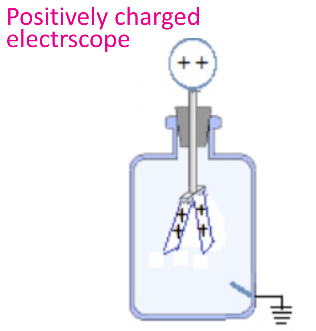


Fig. 13.9 (a)

Detecting the Type of Charge

For the detection of type of charge on a body, electroscope is first charged either positively or negatively. Suppose the electroscope is positively charged as explained before (Fig.13.9-a). Now in order to detect the type of charge on a body, bring the charged body near the disk of the positively charged electroscope. If the divergence of the leaves increases, the body carries positive charge (Fig. 13.9-b). On the other hand if the divergence decreases, the body has negative charge (Fig.13.9-c).

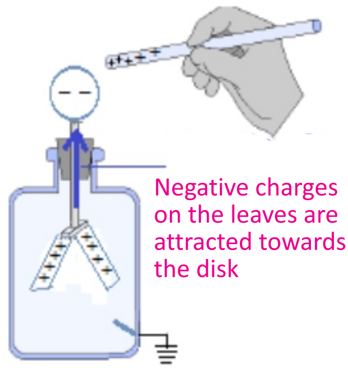


Fig.13.9 (b) Detecting positive charge on body.

Identifying Conductors and Insulators

Electroscope can also be used to distinguish between insulators and conductors. Touch the disk of a charged electroscope with material under test. If the leaves collapse from their diverged position, the body would be a good conductor. If there is no change in the divergence of the leaves, it will show that the body under test is an insulator.

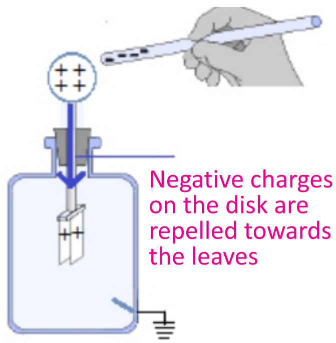


Fig.13.9 (c) Detecting negative charge on body

13. 4 COULOMB'S LAW

We know that a force of attraction or repulsion acts between two charged bodies. How is this force affected when the magnitude of the charge on the two bodies or the distance between them is changed? In order to find the answers of these questions, a French scientist Charles Coulomb (1736–1806) in 1785 experimentally established the fundamental law of electric force between two stationary

charged particles.

Coulomb's Law: *The force of attraction or repulsion between two point charges is directly proportional to the product of the magnitude of charges and inversely proportional to the square of the distance be* $F \propto q_1 q_2$*m. Therefore,*

$$\text{........ (13.1)}$$

$$F \propto \frac{1}{r^2} \qquad \text{........ (13.2)}$$

Combining Eqs. (13.1) and (13.2), we get

$$F = k\,\frac{q_1 q_2}{r^2} \qquad \text{........ (13.3)}$$

Eq. (13.3) is known as Coulomb's law.

where F is the force between the two charges and is called the Coulomb force, q_1 and q_2 are the magnitudes of two charges and 'r' is the distance between the two charges (Fig.13.10). k is the constant of proportionality.

The value of k depends upon the medium between the two charges.

If the medium between the two charges is air, then the value of k in SI units will be $9 \times 10^9\,\mathrm{N\,m^2C^{-2}}$.

Coulomb's law is true only for point charges whose sizes are very small as compared to the distance between them.

Example 13.1: Two bodies are oppositely charged with 500 µC and 100 µC charge. Find the force between the two charges if the distance between them in air is 0.5m.

Solution: Given that, $r = 0.5$ m, $q_1 = 500\,\mu\mathrm{C} = 500 \times 10^{-6}\,\mathrm{C}$,

$q_2 = 100\,\mu\mathrm{C} = 100 \times 10^{-6}\,\mathrm{C}$

Substituting these values in Eq. (13.3), we have

$$F = k\,\frac{q_1 q_2}{r^2} = \frac{9 \times 10^9\,\mathrm{N\,m^2\,C^{-2}} \times 500 \times 10^{-6}\,\mathrm{C} \times 100 \times 10^{-6}\,\mathrm{C}}{(0.5\,\mathrm{m})^2}$$

$$F = 1800\ \mathrm{N}$$

13.5 ELECTRIC FIELD AND ELECTRIC FIELD INTENSITY

According to Coulomb's law, if a unit positive charge q_0 (call it

Point to ponder

Why leaves of charged electroscope collapse if we touch its disk with a metal rod but they do not collapse if we touch the disk with a rubber rod?

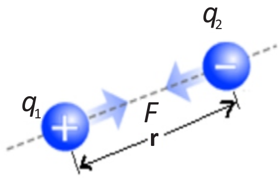


Fig.13.10 (a) Attraction between opposite charges

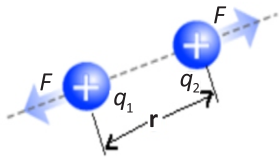


Fig.13.10 (b) Repulsion between similar charges

Point to ponder

On a dry day if we walk in a carpeted room and then touch some conductor we will get a small electric shock! Can we tell why does it happen?

For your information

In SI, the unit of charge is coulomb (C). It is equal to the charge of 6.25×10^{18} electrons. This is very big unit. Usually, charge is measured in micro coulomb. One micro coulomb is equal to 10^{-6}C.

a test charge) is brought near a charge q (call it a field charge) placed in space, the charge q_o will experience a force. The value of this force depends upon the distance between the two charges. If the charge q_0 is moved away from q, this force would decrease till at a certain distance the force would be practically reduced to zero. The charge q_o is then out of the influence of charge q.

The region of space surrounding the charge q in which it exerts a force on the charge q_o is known as electric field of the charge q. Thus, the electric field of a charge is defined as :

The electric field is a region around a charge in which it exerts electrostatic force on another charges.

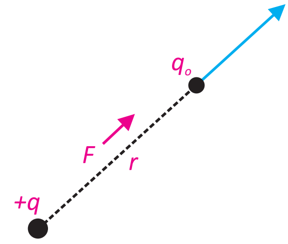


Fig. 13.11: A charge q_o is placed at a distance 'r' from charge $+q$

Electric Field Intensity: *The strength of an electric field at any point in space is known as electric field intensity.*

In order to find the value of electric intensity at a point in the field, of charge $+q$, we place a test charge q_o at that point (Fig. 13.11). If F is the force acting on the test charge q_o, the electric field intensity would be given by

$$E = \frac{F}{q_o} \qquad \text{........ (13.4)}$$

The electric field intensity at any point is defined as the force acting on a unit positive charge placed at that point.

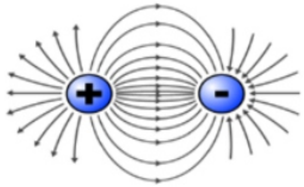
SI unit of electric intensity is $N\,C^{-1}$.

If the electric field due to a given arrangement of charges is known at some point, the force on any particle with charge q placed at that point can be calculated by using the formula:

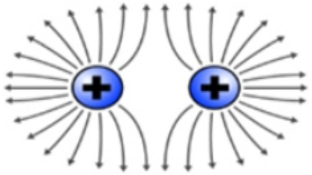
$$F = qE \qquad \text{........ (13.5)}$$

Electric intensity being a force is a vector quantity. Its direction is the same as that of the force acting on the positive test charge. If the test charge is free to move, it will always move in the direction of electric intensity.

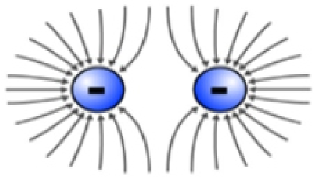
For your information



Electric field lines for two opposite and equal point charges.



Electric field lines for two positive point charges.

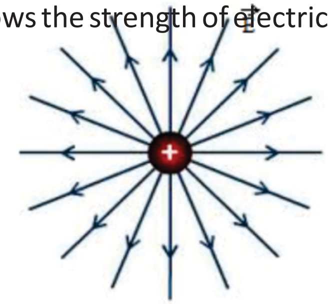


Electric field lines for two negative point charges.

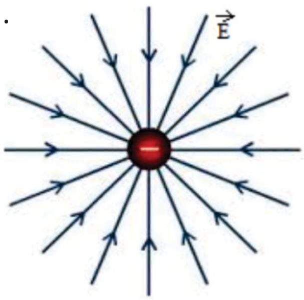
Electric Field Lines

The direction of electric field intensity in an electric field can also be represented by drawing lines. These lines are known

as electric lines of force. These lines were introduced by Michael Faraday. The field lines are imaginary lines around a field charge with an arrow head indicating the direction of force. Field lines are always directed from positive charge towards negative charge. The spacing between the field lines shows the strength of electric field.



Electric field lines for an isolated positive point charge.



Electric field lines for an isolated negative point charge.

13.6 ELECTROSTATIC POTENTIAL

The gravitational potential at a point in the gravitational field is the gravitational potential energy of a unit mass placed at that point. Similarly, the electric potential at any point in the electric field is the electric potential energy of a unit positive charge placed at that point.

Electric Potential : *Electric potential at a point in an electric field is equal to the amount of work done in bringing a unit positive charge from infinity to that point.*

If W is the work done in moving a positive charge q from infinity to a certain point in the field, the electric potential V at this point would be given by

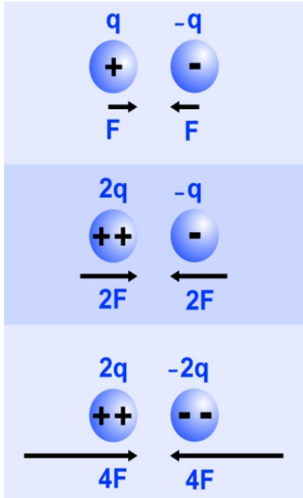
$$V = \frac{W}{q} \quad .... (13.6)$$

It implies that electric potential is measured relative to some reference point and like potential energy we can measure only the change in potential between two points.

Electric potential is a scalar quantity. Its SI unit is volt which is equal to J C^{-1}.

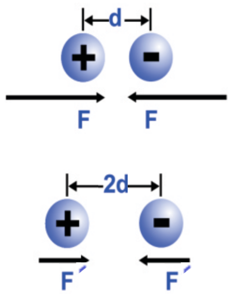
If one joule of work is done against the electric field in bringing one coulomb positive charge from infinity to a point in the

Physics Insight



Variation of magnitude of Coulomb's force between two opposite charges of different magnitudes.

Quick Quiz



If we double the distance between two charges, what will be the change in the force between the charges?

Physics insight

The electrostatic force acting on two charges each of 1 C separated by 1 m is about 9×10^9 N. This force is equal to the gravitational force that the Earth exerts on a billion kilogram object at sea level!

electric field then the potential at that point will be one volt.

A body in gravitational field always tends to move from a point of higher potential energy to a point of lower potential energy. Similarly, when a charge is released in an electric field, it moves from a point of higher potential say A to a point at lower potential say B (Fig.13.12).

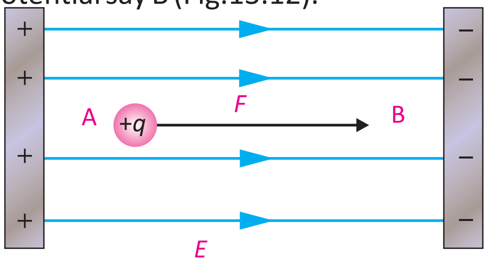


Fig 13.12: Potential difference between two points

If the potential of point A is V_a and that of point B is V_b, the potential energy of the charge at these points will be qV_a and qV_b respectively. The change in potential energy of the charge when it moves from point A to B will be equal to $qV_a - qV_b$. This energy is utilized in doing some useful work. Thus

Energy supplied by the charge = $q\,(V_a - V_b)$ .... (13.7)

If 'q' is one coulomb, then the potential difference between two points becomes equal to the energy supplied by the charge. Thus, we define potential difference between two points as:

The energy supplied by a unit charge as it moves from one point to the other in the direction of the field is called potential difference between two points.

If a positive charge is transferred from a point of lower potential to a point of higher potential i.e., against the field direction, energy would have to be supplied to it.

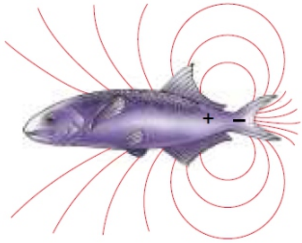
13.7 CAPACITORS AND CAPACITANCE

In order to store the charge, a device which is called capacitor is used. It consists of two thin metal plates, parallel to each other separated by a very small distance (Fig. 13.13). The medium between the two plates is air or a sheet of some

For your information

A tremendous range of field strengths exist in nature. For example, the electric field 30cm away from a light bulb is roughly 5 N C^{-1}, whereas the electron in a hydrogen atom experiences an electric field in the order of 10^{11} N C^{-1} from the atom's nucleus.

Physics of Field Lines



Some animals produce electric fields to detect nearby objects that affect the field.

Do you know?

Electric field lines themselves are not physical entities. They are just used for the pictorial representation of another physical quantity i.e., electric field at various positions.

Point to ponder!

A strong electric field exists in the vicinity of this "Faraday cage". Yet the person inside the cage is not affected. Can you tell why?

insulator. This medium is known as dielectric.

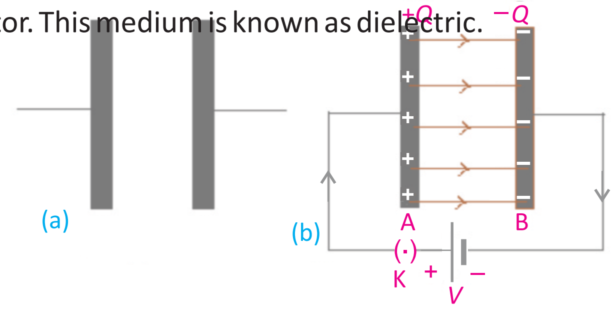


Fig. 13.13 (a) Parallel plate capacitor (b) Plates of capacitor connected with battery

If a capacitor is connected to a battery of V volts, then the battery transfers a charge $+Q$ from plate B to plate A, so that $-Q$ charge appears on plate A and $+Q$ charge appears on plate B.

The charges on each plate attract each other and thus remained bound within the plates. In this way, charge is stored in a capacitor for a long time.

Also, the charge Q stored on plates is directly proportional to the potential difference V across the plates i.e.,

$$Q \quad V$$

$$Q = CV \qquad \text{........(13.8)}$$

where C is the constant of proportionality, called the capacitance of the capacitor and is defined as the ability of the capacitor to store charge. It is given by the ratio of charge and the electric potential as:

$$C = \frac{Q}{V}$$

SI unit of capacitance is farad (F), defined as:

If one coulomb of charge given to the plates of a capacitor produces a potential difference of one volt between the plates of the capacitor then its capacitance would be one farad.

farad is a large unit, usually, we use a smaller unit such as micro farad (μF), nano farad (nF) and pico farad (pF) etc.

Example 13.2: The capacitance of a parallel plate capacitor is 100 μF. If the potential difference between its plates is

Potential and Potential Energy

Electric potential is a characteristic of the field of source charge and is independent of a test charge that may be placed in the field. But, potential energy is a characteristic of both the field and test charge. It is produced due to the interaction of the field and the test charge placed in the field.

50 volts, find the quantity of charge stored on each plate.

Solution: Given that; $V = 50\text{ V}, C = 100\ \mu\text{F} = 100 \times 10^{-6}\text{F}$

Using the formula

$$Q = C\,V$$

Putting the values

$$Q = 100 \times 10^{-6}\text{ F} \times 50\text{ V}$$
$$= 5 \times 10^{-3}\text{ C} = 5\text{ mC}$$

Charge on each plate will be 5 mC, because each plate has equal amount of charge.

Combinations of Capacitors

Capacitors are manufactured with different standard capacitances, and by combining them in series or in parallel, we can get any desired value of the capacitance.

(i) Capacitors in Parallel

In this combination, the left plate of each capacitor is connected to the positive terminal of the battery by a conducting wire. In the same way, the right plate of each capacitor is connected to the negative terminal of the battery (Fig. 13.14).

This type of combination has the following characteristics:

1. Each capacitor connected to a battery of voltage V has the same potential difference V across it. i.e., $V_1 = V_2 = V_3 = V$
2. The charge developed across the plates of each capacitor will be different due to different value of capacitances.
3. The total charge Q supplied by the battery is divided among the various capacitors. Hence,

$$Q = Q_1 + Q_2 + Q_3$$

$$Q = C_1V + C_2V + C_3V$$

or $$\frac{Q}{V} = C_1 + C_2 + C_3$$

or

4. Thus, we can replace the parallel combination of capacitors with one equivalent capacitor having capacitance C_{eq} such that,

$$C_{eq} = C_1 + C_2 + C_3$$

Physics insight

A voltage across a device, such as capacitor, has the same meaning as the potential difference across the device. For instance, if we suppose that the voltage across a capacitor is 12 V, it also means that the potential difference between its plates is 12 V.

For your information

Farad is a bigger unit of capacitance. We generally use the following submultiples:

1 micro farad = 1 μF = 1×10^{-6} F

1 nano farad = 1 nF = 1×10^{-9} F

1 pico farad = 1 pF = 1×10^{-12} F

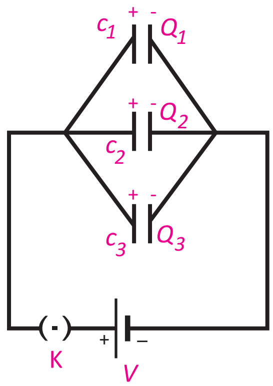


Fig.13.14: Capacitors in parallel combination

For your information

Three factors affect the ability of a capacitor to store charge.

1. Area of the plates
2. Distance between the plates
3. Type of insulator used between the plates.

In the case of 'n' capacitors connected in parallel, the equivalent capacitance is given by

$$C_{eq} = C_1 + C_2 + C_3 + \ldots\ldots + C_n \quad \ldots\ldots(13.9)$$

5. The equivalent capacitance of a parallel combination of capacitors is greater than any of the individual capacitances.

Example 13.3: Three capacitors with capacitances of 3.0 μF, 4.0 μF, and 5.0 μF are arranged in parallel combination with a battery of 6 V, where 1 μF = 10^{-6}F. Find

(a) the total capacitance
(b) the voltage across each capacitor
(c) the quantity of charge on each plate of the capacitor

Solution: Diagram is shown on right.

(a) Total capacitance is given by

$C_{eq} = C_1 + C_2 + C_3$

$C_{eq} = 3.0 \times 10^{-6}\text{F} + 4.0 \times 10^{-6}\text{F} + 5.0 \times 10^{-6}\text{F}$

$C_{eq} = (3+4+5) \times 10^{-6}\text{F} = 12 \times 10^{-6}\text{F}$

$C_{eq} = 12\ \mu\text{F}$

(b) As three capacitors are connected in parallel, the voltage across each capacitor will be same and is equal to the voltage of the battery i.e., 6 V.

(c) Charge on a capacitor with capacitance C_1

$Q_1 = C_1 V$

$Q_1 = 3.0 \times 10^{-6}\text{F} \times 6\text{ V} = (3\text{x}6) \times 10^{-6}\text{F V}$

$Q_1 = 18\ \mu\text{C}$

Similarly, charge on capacitors with capacitances C_2 and C_3 is 24 μC and 30 μC respectively.

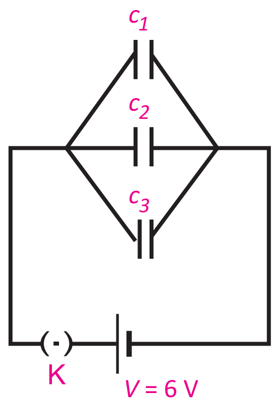
(ii) Capacitors in Series

In this combination, the capacitors are connected side by side i.e., the right plate of one capacitor is connected to the left plate of the next capacitor (Fig. 13.15). This type of combination has the following characteristics:

1. Each capacitor has the same charge across it. If the battery supplies + Q charge to the left plate of the capacitor C_1, due to induction – Q charge is induced on its right plate and +Q charge on the left plate of the capacitor C_2 i.e.,

Quick Quiz

Is the equivalent capacitance of parallel capacitors larger or smaller than the capacitance of any individual capacitor in the combination?



Energy Stored in a Capacitor

Capacitor stores energy in an electric field between two plates in the form of electrostatic potential energy.

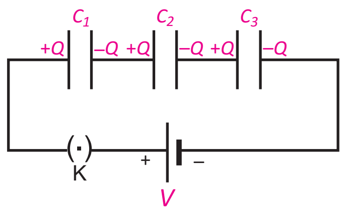


Fig.13.15: capacitors in series combination.

$$Q_1 = Q_2 = Q_3 = Q$$

2. The potential difference across each capacitor is different due to different values of capacitances.

3. The voltage of the battery has been divided among the various capacitors. Hence

$$V = V_1 + V_2 + V_3$$
$$= \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$
$$= Q\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right]$$
$$\frac{V}{Q} = \left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right]$$

4. Thus, we can replace series combination of capacitors with one equivalent capacitor having capacitance C_{eq} i.e.,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

In the case of '*n*' capacitors connected in series, we have

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots\cdots + \frac{1}{C_n} \qquad \ldots\ldots(13.10)$$

Quick Quiz

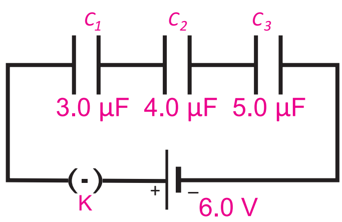
Is the equivalent capacitance of series capacitors larger or smaller than the capacitance of any individual capacitor in the combination?

Example 13.4: Three capacitors with capacitances of 3.0 μF, 4.0 μF, and 5.0 μF are arranged in series combination to a battery of 6V, where 1 μF = 10^{-6}F. Find

(a) the total capacitance of the series combination.
(b) the quantity of charge across each capacitor.
(c) the voltage across each capacitor.

Solution: (a) Diagram is shown on right. For total capacitance,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$
$$\frac{1}{C_{eq}} = \frac{1}{3.0 \times 10^{-6}\,\text{F}} + \frac{1}{4.0 \times 10^{-6}\,\text{F}} + \frac{1}{5.0 \times 10^{-6}\,\text{F}}$$
$$\frac{1}{C_{eq}} = \left[\frac{1}{3} + \frac{1}{4} + \frac{1}{5}\right] \times \frac{1}{10^{-6}\,\text{F}}$$
$$\frac{1}{C_{eq}} = \frac{47}{60} \times \frac{1}{10^{-6}\,\text{F}}$$
$$C_{eq} = 1.3\ \mu\text{F}$$



(b) In series combination, charge across each capacitor is same and can be found as:

$Q = CV = (6.0\,\text{V})(1.3 \times 10^{-6}\,\text{F}) = 7.8\,\mu\text{C}$

(c) Voltage across capacitor $C_1 = V_1 = \dfrac{Q}{C_1} = \dfrac{7.8 \times 10^{-6}\,\text{C}}{3.0 \times 10^{-6}\,\text{F}} = 2.6\,\text{V}$

Voltage across capacitor $C_2 = V_2 = \dfrac{Q}{C_2} = \dfrac{7.8 \times 10^{-6}\,\text{C}}{4.0 \times 10^{-6}\,\text{F}} = 1.95\,\text{V}$

Voltage across capacitor $C_3 = V_3 = \dfrac{Q}{C_3} = \dfrac{7.8 \times 10^{-6}\,\text{C}}{5.0 \times 10^{-6}\,\text{F}} = 1.56\,\text{V}$

13.8 DIFFERENT TYPES OF CAPACITORS

Parallel plate capacitors are not commonly used in most devices because in order to store enough charge their size must be large which is not desirable. A parallel plate capacitor has a dielectric between its plates and is made of a flexible material that can be rolled into the shape of a cylinder. In this way, we can increase the area of each plate while the capacitor can fit into a small space. Some other types of capacitors use chemical reactions to store charge. These are called electrolytic capacitors.

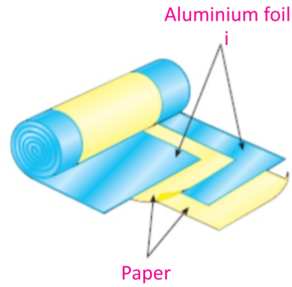


Fig. 13.16: Paper capacitor

Capacitors have different types depending upon their construction and the nature of dielectric used in them.

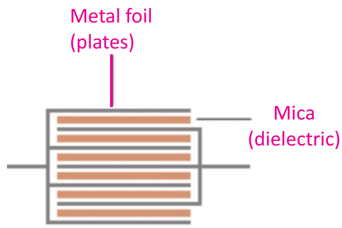


Fig. 13.17: Mica capacitor

Paper capacitor is an example of fixed capacitors (Fig. 13.16). The paper capacitor has a cylindrical shape. Usually, an oiled or greased paper or a thin plastic sheet is used as a dielectric between two aluminium foils. The paper or plastic sheet is firmly rolled in the form of a cylinder and is then enclosed into a plastic case.

Mica capacitor is another example of fixed capacitors. In these capacitors, mica is used as dielectric between the two metal plates (Fig.13.17). Since mica is very fragile, it is enclosed in a plastic case or in a case of some insulator. Wires attached to plates project out of the case for making connections (Fig. 13.18). If the capacitance is to be increased, large number of plates is piled up, one over the other with layers of dielectric in between and alternative plates are connected with each other.

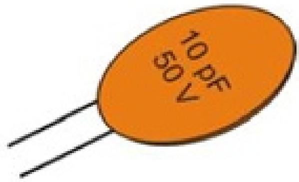


Fig. 13.18: Mica capacitor

In variable type of capacitors, some arrangement is made to change the area of the plates facing each other (Fig. 13.19). It is generally a combination of many capacitors with air as

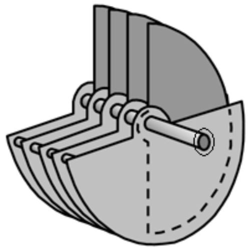


Fig. 13.19: Variable capacitor

dielectric. It consists of two sets of plates. One set remains fixed while the other set can rotate so the distance between the plates does not change and they do not touch each other. The common area of the plates of the two sets which faces each other, determines the value of capacitance. Thus, the capacitance of the capacitor can be increased or decreased by turning the rotatable plates in or out of the space between the static plates. Such capacitors are usually utilized for tuning in radio sets.

An electrolytic capacitor is often used to store large amount of charge at relatively low voltages (Fig.13.20). It consists of a metal foil in contact with an electrolyte—a solution that conducts charge by virtue of the motion of the ions contained in it. When a voltage is applied between the foil and the electrolyte, a thin layer of metal oxide (an insulator) is formed on the foil, and this layer serves as the dielectric. Very large capacitances can be attained because the dielectric layer is very thin.

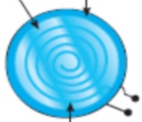


Fig.13.20: Electrolytic capacitor

Uses of Capacitors

Capacitors have wide range of applications in different electrical and electronic circuits. For example, they are used for tuning transmitters, receivers and transistor radios. They are also used for table fans, ceiling fans, exhaust fans, fan motors in air conditioners, coolers, motors washing machines, air conditioners and many other appliances for their smooth working.

Capacitors are also used in electronic circuits of computers etc.

Capacitors can be used to differentiate between high frequency and low frequency signals which make them useful in electronic circuits. For example, capacitors are used in the resonant circuits that tune radios to particular frequencies. Such circuits are called filter circuits. One type of capacitor may not be suitable for all applications. Ceramic capacitors are generally superior to other types and therefore can be used in vast ranges of application.

For your information

All of these devices are capacitors, which store electric charge and energy.

13.9 APPLICATIONS OF ELECTROSTATICS

Static electricity has an important place in our everyday lives which include photocopying, car painting, extracting dust from dirty carpets and from chimneys of industrial machinery

etc.

Electrostatic Air Cleaner

An *electrostatic air cleaner* is used in homes to relieve the discomfort of allergy sufferers. Air mixed with dust and pollen enters the device across a positively charged mesh (Fig.13.21). The airborne particles become positively charged when they make contact with the mesh. Then they pass through a second, negatively charged mesh. The electrostatic force of attraction between the positively charged particles in the air and the negatively charged mesh causes the particles to precipitate out on the surface of the mesh.

Through this process we can remove a very high percentage of contaminants from the air stream.

Electrostatic Powder Painting

Automobile manufacturers use static electricity to paint new cars. The body of a car is charged and then the paint is given the opposite charge by charging the nozzle of the sprayer (Fig.13.22). Due to mutual repulsion, charge particles coming out of the nozzle form a fine mist and are evenly distributed on the surface of the object. The charged paint particles are attracted to the car and stick to the body, just like a charged balloon sticks to a wall. Once the paint dries, it sticks much better to the car and is smoother, because it is uniformly distributed. This is a very effective, efficient and economical wa

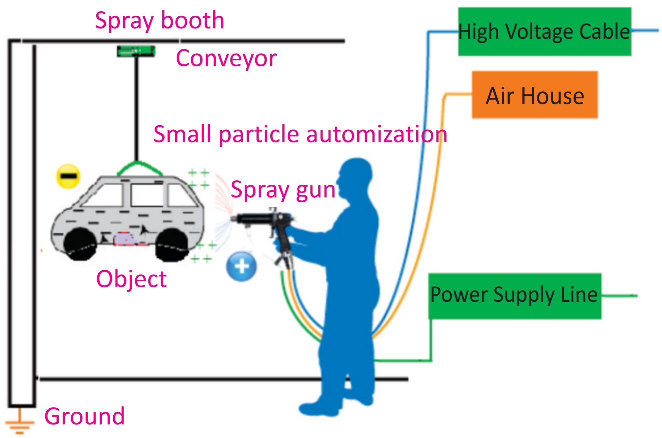


Fig. 13.22: Schematic diagram of electrostatic spray painting system. Car is negatively charged and spray gun is positively charged. As drops have

Point to Ponder!

Capacitor blocks dc but allows ac to pass through a circuit. How does this happen?

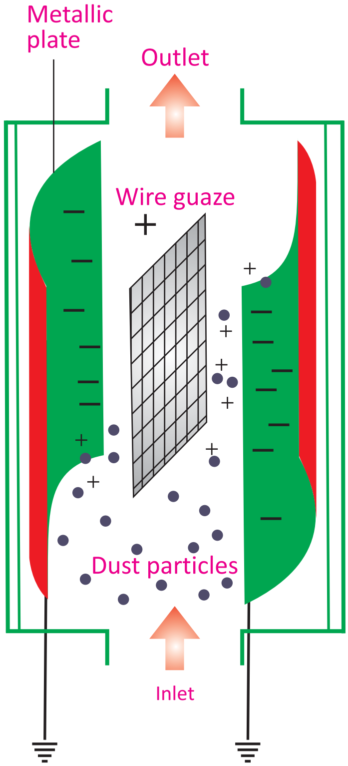


Fig. 13.21

Point to Ponder!

How would you suspend 500,000 pounds of water in the air with no visible means of support? (Hint: build a cloud!)

same charge they repel and give a fine mist of spray

13.10 SOME HAZARDS OF STATIC ELECTRICITY

Lightning

The phenomenon of lightning occurs due to a large quantity of electric charge which builds up in the heavy thunderclouds. The thunderclouds are charged by friction between the water molecules in the thunderclouds and the air molecules. When the charge on the thunderclouds is sufficiently high, It induces opposite charge on the objects present on the ground giving rise to a strong electric field between the cloud and the ground. Suddenly, the charge in cloud jumps to the ground with a violent spark and explosion. This is called lightning.

To prevent lightning from damaging tall buildings, lightning conductors are used. The purpose of the lightning conductor is to provide a steady discharge path for the large amount of negative charge in the air to flow from the top of the building to the Earth. In this way, the chances of lightning damage due to sudden discharge can be minimized.

Fires or Explosions

Static electricity is a major cause of fires and explosions at many places. A fire or an explosion may occur due to excessive build-up of electric charges produced by friction.

Static electricity can be generated by the friction of the gasoline being pumped into a vehicle or container. It can also be produced when we get out of the car or remove an article of clothing. Static charges are dangerous. If static charges are allowed to discharge through the areas where there is petrol vapour a fire can occur.

Dangers of Static Electricity

Static electricity can spark a fire or explosions. Care must be taken to avoid sparks when putting fuel in cars or aircraft. Spark may be produced due to friction between the fuel and the pipe. This can cause a serious explosion. The spark can be avoided if the pipe nozzle is made to conduct by connecting an earthing strap to it. The earthing strap connects the pipe to the ground.

For your information

The energy in lightning is enough to crack bricks and stone in unprotected buildings, and destroy electrical equipments inside. Each bolt of lightning contains about 1000 million joules of energy! This energy is enough to boil a kettle continuously for about two weeks. A flash of lightning is brighter than 10^7 light bulbs each of 100 watt.

For your information

During flight, body of an aeroplane gets charged. As the aeroplane lands, this charge is transferred to ground though the specially designed tyres.

SUMMARY

- Electric charges are of two types, positive charge and negative charge. Like charges repel each other and unlike charges attract each other.
- Electrostatic induction is the process of charging a conductor without any contact with the charging body.
- Coulomb's law states that the force of attraction or repulsion between two charged bodies is directly proportional to the product of the charges and inversely proportional to the square of the distance between them. Mathematically, it is given by

$$F = k\,\frac{q_1 q_2}{r^2}$$

- Electric field is a region of space surrounding a charged body in which a unit positive point charge can experience a force.
- Electric potential at any point in the field is defined as the work done in moving a unit positive charge from infinity to that point. Unit of potential is volt which is equal to one joule of work done in moving one coulomb of positive charge from infinity to that point.
- Capacitor is a device which is used to store electric charge. Capacitance is the ability of a capacitor to store electric charge. Its SI unit is farad (F). If one coulomb of positive charge given to one of the plates of the capacitor develops a potential difference of one volt, then its capacitance will be one farad.
- The equivalent capacitance C_{eq} of a parallel combination of 'n' capacitors is given by

$$C_{eq} = C_1 + C_2 + C_3 + \ldots\ldots + C_n$$

- The equivalent capacitance C_{eq} of a series combination of 'n' capacitors is given by

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots\cdots + \frac{1}{C_n}$$

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the following choices:

i. A positive electric charge

(a) attracts other positive charge (b) repels other positive charge
(c) attracts a neutral charge (d) repels a neutral charge

ii. An object gains excess negative charge after being rubbed against another object, which is:

(a) neutral (b) negatively charged
(c) positively charged (d) either a, b or c

iii. Two uncharged objects A and B are rubbed against each other. When object B is

placed near a negatively charged object C, the two objects repel each other. Which of the following statements is true about object A?

(a) remains uncharged b) becomes positively charged
(c) becomes negatively charged (d) unpredictable

iv. When you rub a plastic rod against your hair several times and put it near some bits of paper, the pieces of papers are attracted towards it. What does this observation indicate?
(a) the rod and the paper are oppositely charged
(b) the rod acquires a positive charge
(c) the rod and the paper have the same charges
(d) the rod acquires a negative charge

v. According to Coulomb's law, what happens to the attraction of two oppositely charged objects as their distance of separation increases?
(a) increases (b) decreases
(c) remains unchanged (d) cannot be determined

vi. The Coulomb's law is valid for the charges which are
(a) moving and point charges (b) moving and non-point charges
(c) stationary and point charges (d) stationary and large size charges

vii. A positive and a negative charge are initially 4 cm apart. When they are moved closer together so that they are now only 1 cm apart, the force between them is
(a) 4 times smaller than before (b) 4 times larger than before
(c) 8 times larger than before (d) 16 times larger than before

viii. Five joules of work is needed to shift 10 C of charge from one place to another. The potential difference between the places is
(a) 0.5 V (b) 2 V
(c) 5 V (d) 10 V

ix. Two small charged spheres are separated by 2 mm. Which of the following would produce the greatest attractive force?
(a) +1q and +4q (b) –1q and –4q
(c) +2q and +2q (d) +2q and –2q

x. Electric field lines
(a) always cross each other
(b) never cross each other
(c) cross each other in the region of strong field
(d) cross each other in the region of weak field

xi. Capacitance is defined as

(a) VC (b) Q/V
(c) QV (d) V/Q

REVIEW QUESTIONS

13.1. How can you show by simple experiments that there are two types of electric charges?
13.2. Describe the method of charging bodies by electrostatic induction.
13.3. How does electrostatic induction differ from charging by friction?
13.4. What is gold leaf electroscope? Discuss its working principle with a labelled diagram.
13.5. Suppose you have a glass rod which becomes positively charged when you rub it with wool. Describe how would you charge the electroscope (i) negatively (ii) positively.
13.6. With the help of electroscope how you can find presence of charge on a body.
13.7. Describe how you would determine the nature of the charge on a body by using electroscope.
13.8. Explain Coulomb's law of electrostatics and write its mathematical form.
13.9. What is meant by electric field and electric intensity?
13.10. Is electric intensity a vector quantity? What will be its direction?
13.11. How would you define potential difference between two points? Define its unit.
13.12. Show that potential difference can be described as energy transfer per unit charge between the two points.
13.13. What do you mean by the capacitance of a capacitor? Define units of capacitance.
13.14. Derive the formula for the equivalent capacitance for a series combination of a number of capacitors.
13.15. Discuss different types of capacitors.
13.16. What is difference between variable and fixed type capacitor?
13.17. Enlist some uses of capacitors.
13.18. Discuss one application of static electricity.
13.19. What are hazards of static electricity?

CONCEPTUAL QUESTIONS

13.1. An electrified rod attracts pieces of paper. After a while these pieces fly away! Why?
13.2. How much negative charge has been removed from a positively charged electroscope, if it has a charge of 7.5×10^{-11} C?
13.3. In what direction will a positively charged particle move in an electric field?
13.4. Does each capacitor carry equal charge in series combination? Explain.
13.5. Each capacitor in parallel combination has equal potential difference between its

two plates. Justify the statement.

13.6. Perhaps you have seen a gasoline truck trailing a metal chain beneath it. What purpose does the chain serve?

13.7. If a high-voltage power line fell across your car while you were in the car, why should you not come out of the car?

13.8. Explain why, a glass rod can be charged by rubbing when held by hand but an iron rod cannot be charged by rubbing, if held by hand?

NUMERICAL PROBLEMS

13.1. The charge of how many negatively charged particles would be equal to 100 μC. Assume charge on one negative particle is 1.6×10^{-19} C? **Ans. (6.25×10^{14})**

13.2. Two point charges $q_1 = 10$ μC and $q_2 = 5$ μC are placed at a distance of 150 cm. What will be the Coulomb's force between them? Also find the direction of the force.

Ans. (0.2 N, the direction of repulsion)

13.3. The force of repulsion between two identical positive charges is 0.8 N, when the charges are 0.1 m apart. Find the value of each charge. **Ans. (9.4×10^{-7} C)**

13.4. Two charges repel each other with a force of 0.1 N when they are 5 cm apart. Find the forces between the same charges when they are 2 cm apart. **Ans. (0.62 N)**

13.5. The electric potential at a point in an electric field is 10^4 V. If a charge of +100 μC is brought from infinity to this point. What would be the amount of work done on it?

Ans.(1 J)

13.6. A point charge of +2 C is transferred from a point at potential 100 V to a point at potential 50 V. What would be the energy supplied by the charge? **Ans. (100 J)**

13.7. A capacitor holds 0.06 coulombs of charge when fully charged by a 9 volt battery. Calculate capacitance of the capacitor. **Ans. (6.67×10^{-3} F)**

13.8. A capacitor holds 0.03 coulombs of charge when fully charged by a 6 volt battery. How much voltage would be required for it to hold 2 coulombs of charge? **Ans.(400 V)**

13.9. Two capacitors of capacitances 6 μF and 12 μF are connected in series with 12 V battery. Find the equivalent capacitance of the combination. Find the charge and the potential difference across each capacitor. **Ans. (4 μF, 48 μC, 8 V, 4 V)**

13.10. Two capacitors of capacitances 6 μF and 12 μF are connected in parallel with a 12 V battery. Find the equivalent capacitance of the combination. Find the charge and the potential difference across each capacitor. **Ans. (18 μF, 72 μC, 144**

Unit 14

CURRENT ELECTRICITY

After studying this unit, students will be able to:

- define electric current.
- describe the concept of conventional current.
- understand the potential difference across a circuit component and name its unit .
- describe Ohm's law and its limitations.
- define resistance and its unit(Ω).
- calculate the equivalent resistance of a number of resistances connected in series and also in parallel.
- describe the factors affecting the resistance of a metallic conductor.
- distinguish between conductors and insulators.
- sketch and interpret the *V-I* characteristics graph for a metallic conductor, a filament lamp and a thermister.
- describe how energy is dissipated in a resistance and explain Joule's law.
- apply the equation $E = I.Vt = I^2Rt = V^2 t/R$ to solve numerical problem.
- calculate the cost of energy when given the cost per kWh.
- distinguish between D.C and A.C.
- identify circuit components such as switches, resistors, batteries etc.
- describe the use of electrical measuring devices like galvanometer, ammeter and voltmeter (construction and working principles not required).
- construct simple series (single path) and parallel circuits (multiple paths).
- predict the behaviour of light bulbs in series and parallel circuit such as for celebration lights.
- state the functions of the live, neutral and earthwires in the domestic main supply.
- state reason why domestic supplies are connected in parallel.
- describe hazards of electricity (damage insulation, overheating of cables, damp conditions).
- explain the use of safety measures in household electricity, (fuse, circuit breaker, earthwire).

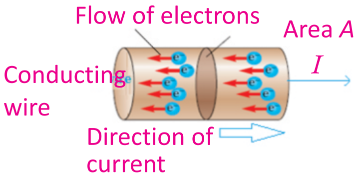
Science, Technology and Society Connections

The students will be able to:

- calculate the total cost of electrical energy used in one month (30 day) at home. suggest ways how it can be reduced without compromising the comforts and benefits of electricity.
- describe the damages of an electric shock from appliances on the human body.
- identify the use of fuses, circuit breakers, earthing, double insulation and other safety measures in relation to household electricity.

Charges in motion constitute electric current. This chapter will introduce you to current electricity and related phenomena such as conventional current, Ohm's law, electric power, Joule's heating effect, hazards of electricity and safety measures. We will also learn how current or voltage is measured in a circuit by electrical devices.

Electric Current



The current is the rate of flow of charge.

14.1 ELECTRIC CURRENT

Most of the electric charge around us is bound in neutral atoms. It is not easy to overcome the electrostatic force of attraction between the nuclei and electrons in an atom. However, in metals some electrons are not tightly bound to nuclei and are free to move around randomly. They have weak force between them and the nucleus. Similarly, in solutions some positive and negative charges can freely move around randomly. When such free charges are exposed to an external electric field, they move in a specific direction, and thus constitute current.

Electric current is produced due to the flow of either positive charge or negative charge or both of charges at the same time. In metals, the current is produced only due to the flow of free electrons i.e., negative charges. In case of electrolyte its molecules in aqueous solution dissociate among positive and negative ions. So the current in electrolyte is produced due to the flow of both positive and negative charges.

The rate of flow of electric charge through any cross-sectional area is called current.

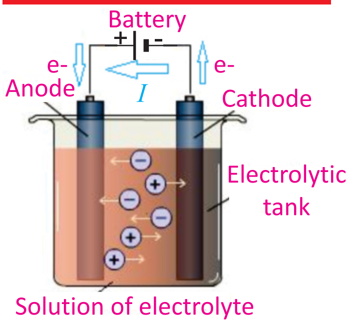
If the charge Q is passing through any area in time t, then current I flowing through it will be given by

$$\text{Current} = \frac{\text{Charge}}{\text{Time}}$$

or $$I = \frac{Q}{t} \quad \text{...........} \quad (14.1)$$

SI unit of current is ampere (A).

For your information



In electrolysis, current is produced due to flow of both positive and negative charges. In the electrolyte, positive ions are attracted to the cathode and negative ions are attracted to the anode. This movement of ions within the electrolyte constitutes an electric current within the internal circuit.

If a charge of one coulomb passes through a cross-sectional area in one second, then current is one ampere. Smaller Units of current are milli ampere (mA), micro ampere (μA), which are defined below as:

$$1\ \text{mA} = 10^{-3}\ \text{A}$$
$$1\ \mu\text{A} = 10^{-6}\ \text{A}$$

Battery is one of the sources of current. The electrochemical reaction inside a battery separates positive and negative electric charges (Fig.14.1). This separation of charges sets up potential difference between the terminals of the battery. When we connect a conducting wire across the terminals of the battery, the charges can move from one terminal to the other due to the potential difference. The chemical energy of the battery changes to electrical potential energy. The electrical potential energy decreases as the charges move around the circuit. This electrical potential energy can be converted to other useful forms of energy (heat, light, sound etc.). It is only the energy which changes form but the number of charge carriers and the charge on each carrier always remains the same (i.e., charge carriers are not used up). Instead of electrical potential energy we use the term electric potential which is potential energy per unit charge.

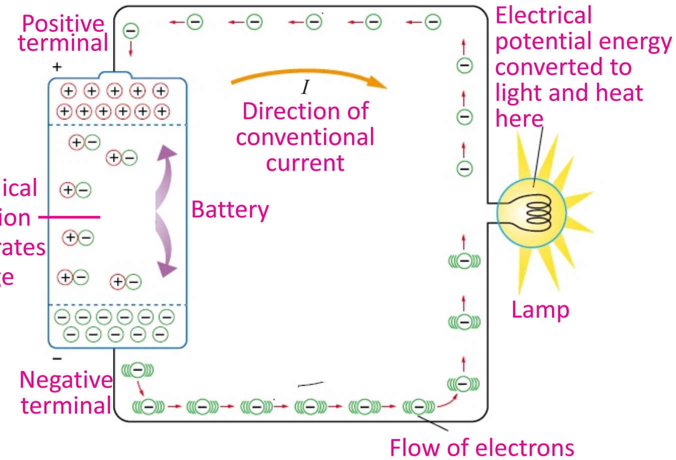


Fig.14.1: Schematic diagram of battery as a current source

Example 14.1: If 0.5 C charge passes through a wire in 10 s, then what will be the value of current flowing through the wire?

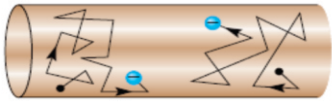
Solution: Given that, $Q = 0.5$ C, $t = 10$ s, therefore by using

$$I = Q/t = 0.5\ \text{C}/10\ \text{s} = 0.05\ \text{A} = 50\ \text{mA}$$

Quick Quiz

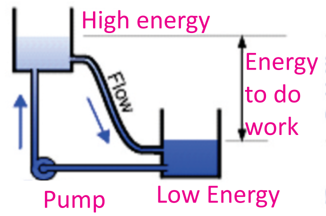
How long does it take a current of 10 mA to deliver 30 C of charge?

Connection



In the absence of any external source no current passes through the conductor due to random motion of electrons.

For your information



A battery raises electric charge back up to higher voltage (energy) just like a pump which pushes water back up to high energy so it can flow and do work again.

Conventional Current

Before the idea of free electrons which constitute current in metals, it was thought that current in conductors flows due to the motion of positive charges. Therefore, this convention is still in use. We can understand the concept of conventional current from the following analogies.

We know that when the ends of heated copper wire are at different temperatures, heat energy flows from the end at higher temperature to the end at lower temperature. The flow stops when both ends reach the same temperature. Water in a pipe also flows from higher level to the lower level. Similarly, when a conductor is connected to a battery, it pushes charges to flow current from higher potential to the lower potential (Fig. 14.2). The flow of current continues as long as there is a potential difference.

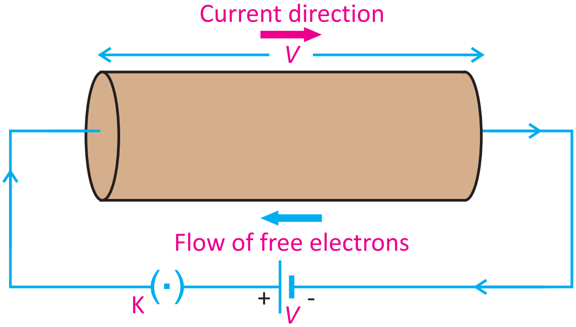


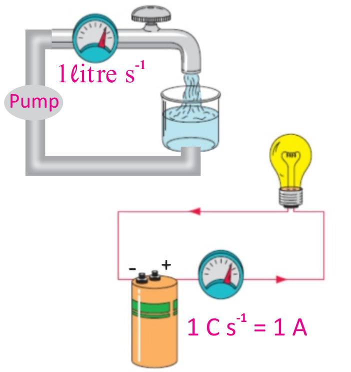
Fig. 14.2: Current flows in a conductor when it is connected to a battery

Conventional current is defined as:

Current flowing from positive to negative terminal of a battery due to the flow of positive charges is called conventional current

Conventional current produces the same effect as the current flowing from negative terminal to the positive terminal due to the flow of negative charges.

Physics insight



The flow of charge in a circuit is like the flow of water in a pipe except that a return wire is needed in order to have a complete conducting path.

The Measurement of Current

How can we come to know that current has been established in the conductor? For this purpose, we use different electrical instruments which detect the current in the circuit. Galvanometer and ammeter are some common examples of current measuring instruments.

Galvanometer is very sensitive instrument and can detect small current in a circuit (Fig.14.3). A current of few milliamperes is sufficient to cause full scale deflection in it.
While making the connections polarity of the terminals of the galvanometer should be taken into consideration. Generally, the terminal of the galvanometer with red colour shows the positive polarity while that of with black colour shows the negative polarity. An ideal galvanometer should have very small resistance to pass the maximum current in the circuit.
After suitable modification galvanometer can be converted into an ammeter (Fig. 14.4). A large current of the range such as 1 A or 10 A can be measured by means of ammeter. Like galvanometer, ammeter is also connected in series, so the current flowing in the circuit also passes through the ammeter (Fig.14.5).

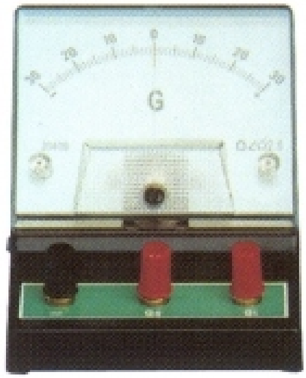


Fig.14.3: A galvanometer

Fig.14.4: An ammeter

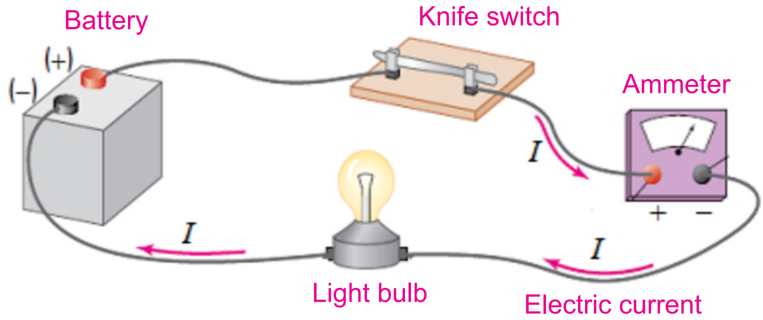


Fig.14.5: Schematic diagram showing the measurement of current

14.2 POTENTIAL DIFFERENCE

When one end A of a conductor is connected to the positive terminal and its other end B is connected to the negative terminal of the battery, then the potential at A becomes higher than the potential at B (Fig.14.6).

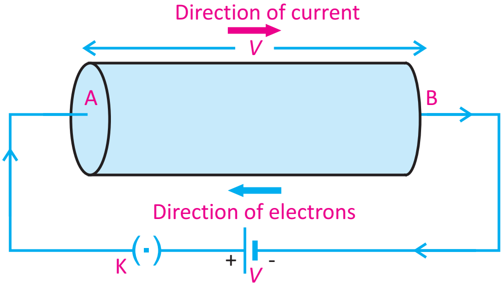


Fig.14.6

Do you know?

The galvanometer has been named after Luigi Galvano (1737-1798). He, while dissecting a frog's leg, discovered that dissimilar metals touching the leg caused it to twitch. This chance discovery, the invention of the chemical cell and the battery.

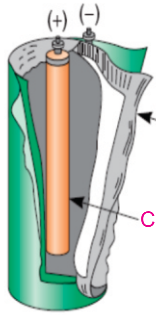
This causes a potential difference between the two ends of the conductor. The flow of current continues as long as there is a potential difference. The agency which provides the potential difference for the steady flow of current in the copper wire is the battery. As the current flows from higher potential to the lower potential through the conductor, the electrical energy (due to current) is converted into other forms (heat and light etc.).

When current flows through the conductor, it experiences a resistance in the conductor by collisions with atoms of the conductor. The energy supplied by the battery is utilized in overcoming this resistance and is dissipated as heat and other forms of energy. The dissipation of this energy is accounted for by the potential difference across the two ends of the light bulb. Thus

Potential difference across the two ends of a conductor causes the dissipation of electrical energy into other forms of energy as charges flow through the circuit.

SI unit of potential difference is volt. A potential difference of 1 V across a bulb means that each coulomb of charge or 1 ampere of current that passes through the bulb consumes 1 joule of energy. When a bulb is lit, the energy is taken from the current and is transformed into light and heat energy.

For your information



In a dry cell chemical energy changes into electric energy.

Do you know?

The volt is named after the Italian physicist Alessandro Volta (1745-1827), who developed the first practical electric battery, known as a voltaic pile. Because potential difference is measured in units of volts, it is sometimes referred to as voltage.

14.3 ELECTROMOTIVE FORCE (e.m.f)

A source of electromotive force (e.m.f.) converts non-electrical energy (chemical, thermal, mechanical etc.) into electrical energy. Examples of sources of e.m.f. are batteries, thermocouples and generators. When a conductor is connected to a battery, current flows through it due to potential difference.

For the continuous flow of current through a wire, battery supplies energy to the charges. The positive charge leaves the positive terminal of the battery, passes through the conductor and reaches the negative terminal of the battery. As a positive charge enters the battery at its lower potential point (negative terminal), the battery must supply energy, say W to the positive charge to drive it to a point of higher

potential i.e., positive terminal. Now we define e.m.f. of the source as:

It is the energy supplied by a battery to a unit positive charge when it flows through the closed circuit. Or The energy converted from non-electrical forms to electrical form when one coulomb of positive charge passes through the battery.

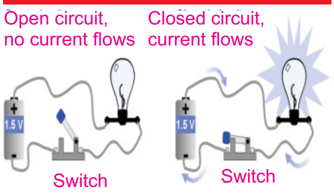
Thus $$e.m.f = \frac{Energy}{Charge}$$

or $$E = \frac{W}{Q} \qquad ....(14.2)$$

where E is the e.m.f., W is energy converted from non-electrical forms to electrical form and Q is positive charge. The unit for e.m.f. is JC^{-1} which is equal to volt (V) in SI system. Hence, if the e.m.f. of the battery is 2 V, the total energy supplied by the battery is 2 joules when one coulomb of charge flows through the closed circuit.

Fig.14.7: A voltmeter

For your information



The Measurement of Potential Difference

The potential difference across a circuit component (e.g. light bulb) can be measured by a voltmeter (Fig. 14.7) connected directly across the terminals of the component. The positive terminal of the battery is connected to the positive terminal of the voltmeter and the negative terminal of the battery is connected to the negative terminal of the voltmeter.

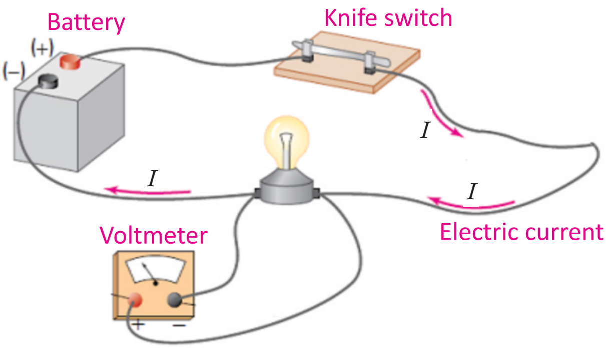


Fig. 14.8: Schematic diagram for measuring potential difference in a circuit

An ideal voltmeter should have very large value of resistance so that no current passes through it. Voltmeter is always connected in parallel with the device across which the potential difference is to be measured (Fig. 14.8).

For your information

A digital multimeter can be used to measure current, resistance and potential difference. Here, the multimeter is in voltmeter mode to measure the potential difference across a battery.

The Measurement of e.m.f

In general, e.m.f refers to the potential difference across the terminals of the battery when it is not driving current in the external circuit. So in order to measure e.m.f of the battery we connect voltmeter directly with the terminals of the battery as shown in Fig. 14.9.

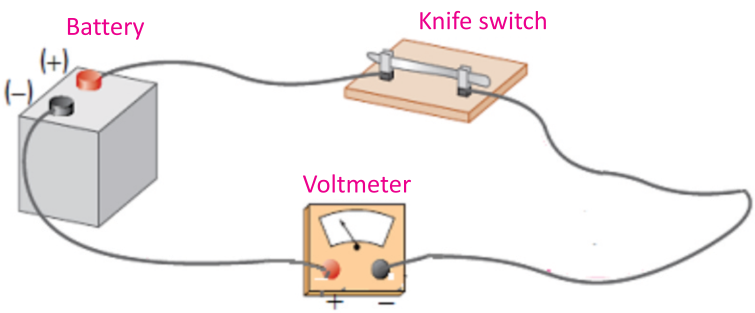


Fig. 14.9: Schematic diagram for measuring e.m.f. of the battery

14.4 OHM'S LAW

Activity 14.1: Take a nichrome wire of about 50 cm length and apply a potential difference of 1.5 V from a battery (Fig.14.10a). Measure the current flowing through the wire using an ammeter connected to it in series. Also measure the potential difference across the wire using a voltmeter connected across it. Obtain a set of readings for I and V, by increasing the number of cells. Plot a graph between I and V. This will be a straight line (Fig.14.10-b).

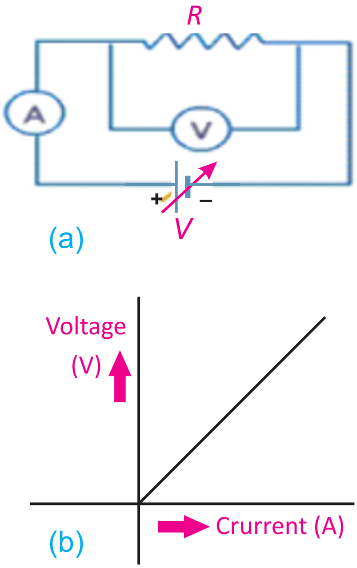


Fig. 14.10

If V is the potential difference across the two ends of any conductor, then current I will flow through it. The value of the current changes with the changes in potential difference and is explained by Ohm's law, stated as:

The amount of current passing through a conductor is directly proportional to the potential difference applied across its ends, provided the temperature and the physical state of the conductor does not change.

i.e., $I \quad V$ or $V \quad I$

or $V = IR$

where R is the constant of proportionality, and is the resistance of the conductors. Its SI unit is ohm, denoted by a

symbol Ω. If a graph is plotted between the current I and the potential difference V, a straight line will be obtained.

Resistance: *The property of a substance which offers opposition to the flow of current through it is called its resistance.*

This opposition comes from the collisions of moving electrons with atoms of the substance.

Unit of Resistance: ohm

The SI unit of resistance R is ohm. If we put $V = 1$ V, and $I = 1$ A, the value of R will be 1 Ω. Thus

When a potential difference of one volt is applied across the ends of a conductor and one ampere of current passes through it, then its resistance will be one ohm.

Example 14.2: Reading on voltmeter connected across a heating element is 60 V. The amount of current passing through the heating element measured by an ammeter is 2 A. What is the resistance of the heating coil of the element?

Solution: Given that, $V = 60$ V, $I = 2$ A

Using Ohm's law

$$V = IR$$

or $$R = \frac{V}{I} = \frac{60\text{ V}}{2\text{ A}} = 30\text{ V A}^{-1} = 30\ \Omega$$

14.5 *V-I* Characteristics of Ohmic and Non Ohmic Conductors

Ohm's law is valid only for certain materials.

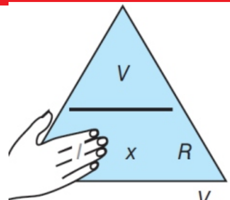
Materials that obey Ohm's law, and hence have a constant resistance over a wide range of voltages, are said to be ohmic. Materials having resistance that changes with voltage or current are non-ohmic.

Ohmic conductors have a linear voltage-current relationship over a large range of applied voltages (Fig. 14.11-a). The straight line shows a constant ratio between voltage and current. Ohm's law is obeyed. For example, most metals show ohmic behaviour.

For your understanding

1. In order to measure current through a resistance, ammeter is always connected in series with the resistance.
2. In order to measure potential difference across a resistance, voltmeter is always connected in parallel with the resistance.

Physics Insights



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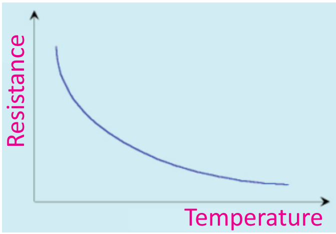


A thermister is a temperature dependent resistor and its resistance decreases as temperature rises. Thermister is used in a circuit that senses temperature change.

Non ohmic materials have a non linear voltage-current relationship. For example, filament lamp, and thermister. The resistance of filament rises (current decreases) as it gets hotter, which is shown by the gradient getting steeper (Fig.14.11-b). A thermister (a heat sensitive resistor) behaves in the opposite way. Its resistance decreases (current increases) as it gets hotter (Fig. 14.11-c). This is because on heating, more free electrons become available for conduction of current.

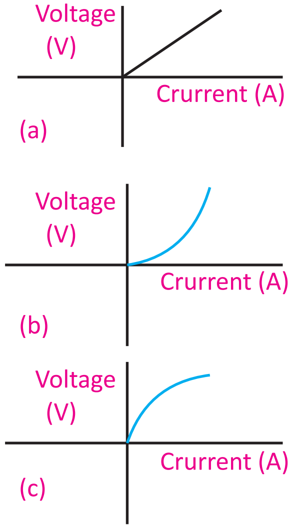


Fig.14.11: Voltage vs current graph for
(a) Fixed resistance
(b) Filament lamp
(c) Thermister

14.6 FACTORS AFFECTING RESISTANCE

A short pipe offers less resistance to water flow than a long pipe. Also the pipe with larger cross sectional area offers less resistance than the pipe having smaller cross sectional area. Same is the case for the resistance of wires that carry current. The resistance of a wire depends both on the cross sectional area and length of the wire and on the nature of the material of the wire. Thick wires have less resistance than thin wires. Longer wires have more resistance than short wires. Copper wire has less resistance than steel wire of the same size. Electrical resistance also depends on temperature.

At a certain temperature and for a particular substance

1. The resistance R of the wire is directly proportional to the length of the wire i.e.,

$$R \propto L \quad .... \quad (14.3)$$

It means, if we double the length of the wire, its resistance will also be doubled, and if its length is halved, its resistance would become one half.

2. The resistance R of the wire is inversely proportional to the area of cross section A of the wire i.e.,

$$R \propto \frac{1}{A} \quad .... \quad (14.4)$$

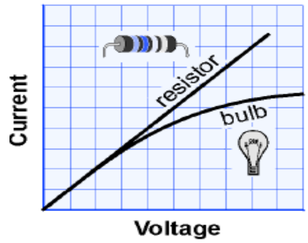
It means that a thick wire would have smaller resistance than a thin wire.

After combining the two equations, we get

$$R \propto \frac{L}{A}$$

$$R = \rho \frac{L}{A} \quad .... \quad (14.5)$$

Point to ponder!



The current versus voltage graph of a resistor is a straight line with a constant slope. The graph for light bulb is curved with a decreasing slope. What can you infer from this?

where 'ρ' is the constant of proportionality, known as specific resistance. Its value depends upon the nature of conductor i.e., copper, iron, tin, and silver would each have a different values of 'ρ'.

If we put $L = 1$ m, and $A = 1\ \text{m}^2$ in Eq. (14.5), then $R = \rho$, i.e., the resistance of one metre cube of a substance is equal to its specific resistance. The unit of 'ρ' is ohm-metre (Ω m).

Example 14.3: If the length of copper wire is 1 m and its diameter is 2 mm, then find the resistance of this copper wire.

Solution: Given that, length of the wire L = 1 m, diameter of the wire d = 2 mm = 2×10^{-3}m

Cross sectional area of the wire

$$A = \pi d^2/4 = \frac{3.14\times(2\times10^{-3})^2\ \text{m}^2}{\text{ی}}$$

$$A = 3.14\times10^{-6}\ \text{m}^2$$

Specific resistance of copper $\rho = 1.69 \times 10^{-8}\ \Omega\text{m}$

Now we have $R = \rho \times L/A = 1.69\times10^{-8}\ \Omega\text{m} \times 1\ \text{m}/3.14\times10^{-6}\ \text{m}^2$

$$R = 0.54\times10^{-2}\ \Omega$$

Interesting Information

Diamond does not conduct electricity, because it has no free electrons. However, it is very good at conducting heat because its particles are very firmly bonded together. Jewellers can tell if a diamond is a real diamond or a fake one made from glass, by holding it to their lips. A real diamond feels very cold due to good ability of transferring heat four or five times better than copper.

14.7 CONDUCTORS

Why do we always use metal wires for conduction of electricity? Because, they are good conductors of electricity and offer less resistance to the flow of current. But how can they conduct electricity with much ease? Metals like silver and copper have excess of free electrons which are not held strongly with any particular atom of metals. These free electrons move randomly in all directions inside metals. When we apply an external electric field these electrons can easily move in a specific direction. This movement of free electrons in a particular direction under the influence of an external field causes the flow of current in metal wires. The resistance of conductors increases with increase in temperature. This is due to increase in the number of collisions of electrons with themselves and with the atoms of the metals.

For your information

Metal	Specific resistance ($10^{-8}\Omega$ m)
Silver	1.7
Copper	1.69
Aluminium	2.75
Tungsten	5.25
Platinum	10.6
Iron	9.8
Nichrome	100
Graphite	3500

14.8 INSULATORS

All materials contain electrons. The electrons in insulators, like rubber, however, are not free to move. They are tightly

bound inside atoms. Hence, current cannot flow through an insulator because there are no free electrons for the flow of current. Insulators have very large value of resistance. Insulators can be easily charged by friction and the induced charge remains static on their surface. Other examples of insulators are glass, wood, plastic, fur, silk, etc.

14.9 COMBINATION OF RESISTORS

(i) Series combination (ii) Parallel combination
Resistors can be connected in two ways.

(i) Series Combination

In series combination, resistors are connected end to end (Fig. 14.12) and electric current has a single path through the circuit. This means that the current passing through each resistor is the same.

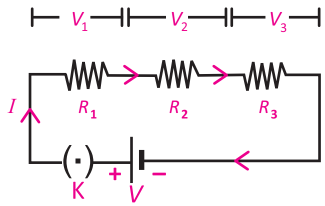


Fig.14.12: Three resistors in series combination

Equivalent Resistance of Series Circuit

The total voltage in a series circuit divides among the individual resistors so the sum of the voltage across the resistance of each individual resistor is equal to the total voltage supplied by the source. Thus, we can write as

$$V = V_1 + V_2 + V_3 \quad \text{.........} \ (14.6)$$

where V is the voltage across the battery, and V_1, V_2, V_3 are the voltages across resistors R_1, R_2 and R_3 respectively. If I is the current passing through each resistor, then from Ohm's law

$$V = IR_1 + IR_2 + IR_3$$

$$V = I(R_1 + R_2 + R_3) \quad \text{.........} \ (14.7)$$

We can replace the combination of resistors with a single resistor called the equivalent resistance R_e such that the same current passes through the circuit. From Ohm's law

$$V = I R_e$$

Thus, Eq. (14.7) becomes

$$I R_e = I(R_1 + R_2 + R_3)$$

$$R_e = R_1 + R_2 + R_3 \quad \text{.........} \ (14.8)$$

Thus, the equivalent resistance of a series combination is equal to the sum of the individual resistances of the

Do you know?

We use heating effect of an electric current for different purposes. For example, when a current flows through the filament of a bulb, it glows white hot and gives out light. Electric heaters have very thin wires that glow red hot when a current flows.

Quick Quiz

Which metal is used as the filament of an electric bulb? Explain with reason.

combination.

If resistances R_1, R_2, R_3, ..., R_n are connected in series, then the equivalent resistance of the combination will be given by

$$R_e = R_1 + R_2 + R_3 + ... + R_n$$

Example 14.4: If two resistors of 6 kΩ and 4 kΩ are connected in series across a 10 V battery, then find the following quantities:

(a) Equivalent resistance of the series combination.
(b) The current flowing through each of the resistance.
(c) Potential difference across each of the resistances.

Solution: Given that, R_1= 6 kΩ and R_2= 4 kΩ

(a) The equivalent resistance of the series combination is $R_e = R_1 + R_2$

or $\quad R_e$ = 6 kΩ + 4 kΩ =10 kΩ

(b) If a battery of 10 V is connected across the equivalent resistance R_e, the current passing through it is given by

$$I = \frac{V}{R_e} = \frac{10\text{ V}}{10\text{ k}\Omega} = 1.0 \times 10^{-3}\text{ A} = 1\text{ m A}$$

In the case of series combination same current would pass through each resistance. Hence, current through R_1 and R_2 would be equal to 1 mA.

(c) Potential difference across $R_1 = V_1 = IR = 1.0 \times 10^{-3}\text{ A} \times 6\text{ k}\Omega = 6\text{ V}$

Potential difference across $R_2 = V_2 = IR_2 = 1.0 \times 10^{-3}\text{ A} \times 4\text{ k}\Omega = 4\text{ V}$

Point to ponder!

A bird can sit harmlessly on high tension wire. But it must not reach and grab neighboring wire. Do you know why?

(ii) Parallel Combination

In parallel combination one end of each resistor is connected with positive terminal of the battery while the other end of each resistor is connected with the negative terminal of the battery (Fig.14.13). Therefore, the voltage is same across each resistor which is equal to the voltage of the battery i.e.,

$$V = V_1 = V_2 = V_3$$

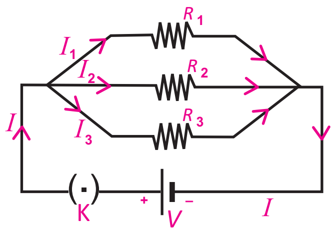


Fig 14.13: Three resistors in parallel combination

Equivalent Resistance of Parallel Circuit

In parallel circuit, the total current is equal the sum of the currents in various resistances i.e.,

$$I = I_1 + I_2 + I_3 \quad .... (14.9)$$

Since the voltage across each resistance is V, so by Ohm's law

$$I_1 = \frac{V}{R_1},\ I_2 = \frac{V}{R_2} \text{ and } I_3 = \frac{V}{R_3}$$

Thus, Eq.14.9 becomes

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) \quad \text{.........} \quad (14.10)$$

We can replace the combination of resistors with a single resistor called the equivalent resistance R_e such that the same current passes through the circuit. From Ohm's law $I = V/R_e$. Thus, Eq. 14.10 becomes

$$\frac{V}{R_e} = V\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \text{.........} \quad (14.11)$$

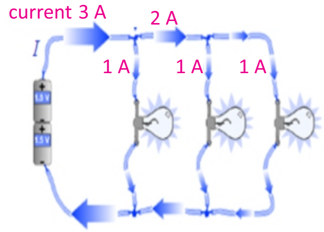
Thus, the reciprocal of equivalent resistance of a parallel combination is sum of the reciprocals of the individual resistances, which is less than the smallest resistance of the combination. If resistances R_1, R_2, R_3, ..., R_n are connected in parallel, then the equivalent resistance of the combination will be given by

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{.........} + \frac{1}{R_n}$$

Parallel circuits have two big advantages over series circuits.

1. Each device in the circuit receives the full battery voltage.
2. Each device in the circuit may be turned off independently without stopping the current flowing to the other devices in the circuit. This principle is used in household wiring.

For your information



In parallel circuit current divides into branches.

Example 14.5: If in the circuit (Fig. 14.13), R_1= 2 Ω, R_2= 3 Ω, R_3= 6 Ω, and V= 6 V, then find the following quantities:

(a) equivalent resistance of the circuit.

(b) current passing through each resistance.

(c) The total current of the circuit.

Solution: **(a)** As the resistors are connected in parallel, equivalent resistance R_e of the combination is give by

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

For your information

A circuit diagram is a symbolic method of describing a real circuit. The electric symbols used in circuit diagrams are standard, so anyone familiar with electricity can interpret a circuit diagram.

$$\frac{1}{R_e} = \frac{1}{2\Omega} + \frac{1}{3\Omega} + \frac{1}{6\Omega} = \left[\frac{1}{2} + \frac{1}{3} + \frac{1}{6}\right] \times \frac{1}{\Omega}$$

$$\frac{1}{R_e} = \frac{6}{6\Omega}$$

or $R_e = 1\Omega$

This value is smaller than the lowest value of the resistance in the combination which is always the case in parallel circuits.

(b) In parallel combination, the potential difference across each of the resistance is same and is equal to the potential of the battery, which is 6 V. Therefore,

Current through R_1 is $I_1 = \frac{V}{R_1} = \frac{6\text{ V}}{2\ \Omega} = 3\text{ A}$

Current through R_2 is $I_2 = \frac{V}{R_2} = \frac{6\text{ V}}{3\ \Omega} = 2\text{ A}$

Current through R_3 is $I_3 = \frac{V}{R_3} = \frac{6\text{ V}}{6\ \Omega} = 1\text{ A}$

(c) Sum of the currents passing through the resistances in parallel combination is equal to the total current I of the circuit. Therefore, total current is 6 A.

Activity 14.2: Connect a battery to a small 2.5 V light bulb and observe the brightness of the bulb. Connect a second light bulb in parallel with the first and observe the brightness of the bulbs. Now add a third bulb in parallel with the others and note the brightness of the bulbs. Does the brightness of the bulbs differs from the bulbs connected in the series with the battery? Explain.

14.10 ELECTRICAL ENERGY AND JOULE'S LAW

Turbine runs generator to produce electrical energy when water falls on it from higher gravitational potential to lower gravitational potential. Similarly, when charge moves from a higher electric potential to a lower potential, it delivers electric current. Thus, the process during which charges continuously move from a higher potential to a lower

For your information

If the values of all the resistors in a parallel circuit are the same, the overall resistance can be determined by

$$\frac{1}{R_e} = \frac{N}{R}$$

i.e., $$R_e = \frac{R}{N}$$

where N is the total number of resistors and R is the resistance of each individual resistor.

For your information

Typical power ratings

Appliance	Power (watts)
Electric stove	5,000
Electric heater	1,500
Hair dryer	1,000
Iron	800
Washing machine	750
Light bulb	100
Small fan	50
Clock radio	10

potential, becomes a continuous source of electrical energy.

Consider two points with a potential difference of V volts. If one coulomb of charge passes between these points; the amount of energy delivered by the charge would be V joule. Hence, when *Q* coulomb of charge flows between these two points, then we will get *QV* joules of energy. If we represent this energy by *W*, then

Electrical energy supplied by *Q* charge $W = QV$ joules

Now current, when charges *Q* flow in time *t*, is defined as:

$$I = \frac{Q}{t}$$

$$\text{or} \quad Q = It$$

So the energy supplied by *Q* charge in t seconds = $W = V \times I \times t$

This electrical energy can be converted into heat and other forms in the circuit.

From Ohm's law, we have $V = IR$

So the energy supplied by *Q* charge is $W = I^2Rt = \frac{V^2t}{R}$

This equation is called Joule's law, stated as:

The amount of heat generated in a resistance due to flow of charges is equal to the product of square of current I, resistance R and the time duration t.

This energy can be utilized for different useful purposes. For example, bulb converts this energy into light and heat, heater and iron into heat, and fans into mechanical energy. Usually, this energy appears as heat in the resistance. This is the reason that we get heat when current passes through a heater.

Example 14.6: If a current of 0.5 A passes through a bulb connected across a battery of 6 *V* for 20 seconds, then find the rate of energy transferred to the bulb. Also find the resistance of the bulb.

Solution: Given that, $I = 0.5$ A, V=6 V, $t = 20$ s

Now using the formula,

Energy $W = VIt$

we get, Energy = 6 V × 0.5 A × 20 s = 60 J

So the rate of energy transferred must be 60 J in 20 s or 3 J s^{-1} or 3 watt.

For your information

Energy-saver light bulbs transform much more of the electrical energy into light and much less into wasted heat energy. An energy-saver light bulb that uses 11 J of electrical energy each second gives the same amount of light as an "ordinary" incandescent bulb that uses 60 J of electrical energy each second.

For Your Understanding

All electrical appliances have power rating, given in watts or kilowatts. An appliance with a power rating of 1W transfers 1 joule of electrical energy each second. So a 60 W light bulb converts 60 J of electrical energy each second into light energy and heat energy. To find out the total energy an appliance transfers from the mains, we need to know the number of joules transferred each second and the number of seconds for which the appliance is ON.

Now using, Energy = $W = I^2Rt$

We get resistance as

$$3 = (0.5)^2 \times R \times 20$$
$$R = 3 \times 1/20 \times 1/0.25 = 3/5 = 0.6\ \Omega$$

14.11 ELECTRIC POWER

The amount of energy supplied by current in unit time is known as electric power.

Hence power P can be determined by the formula

$$\text{Electric power } P = \text{electrical energy/time} = W/t$$

where W is the electrical energy given by

$$W = QV$$

Therefore, above equation becomes

$$\text{Electric power} \quad P = \frac{QV}{t} = IV = I^2R$$

When current I is passing through a resistor R, the electric power that generates heat in the resistance is given by I^2R. The unit of electric power is watt which is equal to one joule per second (1 Js^{-1}). It is represented by the symbol W. Electric bulbs commonly used in houses consume 25 W, 40 W, 60 W, 75 W and 100 W of electric power.

Example 14.7: The resistance of an electric bulb is 500 Ω. Find the power consumed by the bulb when a potential difference of 250 V is applied across its ends.

Solution: Given that, $R = 500\ \Omega$, $V = 250$ V

Using the formula, $I = V/R$

$$I = 250\text{ V}/500\ \Omega = 0.5\text{ A}$$

and Power $P = I^2R = (0.5\text{ A})^2 \times 500\ \Omega = 125$ W

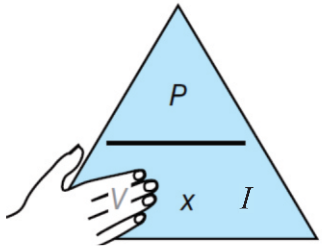
Kilowatt-Hour

Electric energy is commonly consumed in very large quantity for the measurement of which joule is a very small unit. Hence, a very large unit of electric energy is needed which is called kilowatt-hour. It is defined as

Electrical grounding

The Earth is a fairly good electrical conductor. Hence, if a charged object is connected with the Earth by a piece of metal, the charge is conducted away from the object to the Earth. This convenient method of removing the charge from an object is called **grounding** the object. As a safety measure, the metal shells of electrical appliances are grounded through special wires that give electric charges in the shells paths to the Earth. The round post in the familiar three-prong electric plug is the ground connection.

Remembering power formula



cover V to find V = $\frac{P}{I}$

Do you know?

Although the light intensity from a 60 W incandescent light bulb appears to be constant, the current in the bulb fluctuates 50 times each second between -0.71 A and 0.71 A. The light appears to be steady because the fluctuations are too rapid for our eyes to perceive.

The amount of energy delivered by a power of one kilowatt in one hour is called kilowatt-hour.

One kilowatt-hour 1 kWh = 1000 W × 1 hour

$$= 1000\ \text{W} \times (3600\ \text{s})$$
$$= 36 \times 10^5\ \text{J} = 3.6\ \text{MJ}$$

The energy in kilowatt-hour can be obtained by the following formula:

The amount of energy in kilowatt-hour

$$= \frac{\textit{watt x time of use in hours}}{1000}$$

The electric meter installed in our houses measures the consumption of electric energy in the units of kilowatt-hour according to which we pay our electricity bills. If the cost of one kilowatt-hour i.e., one unit is known, we can calculate the amount of electricity bill by the following formula:

Cost of electricity = number of units consumed × cost of one unit

$$= \frac{\textit{watt x time of use in hours}}{1000} \textit{ x cost of one unit}$$

Example 14.8: Calculate the one month cost of using 50 W energy saver for 8 hours daily in your study room. Assume that the price of a unit is Rs. 12.

Solution: Given that, Power = 50 W = 0.05 kW, time = 8 hours

Number of units consumed = 8 × 30 × 0.05 = 12 units

Therefore, total cost = 12 × 12 = Rs. 144

14.12 DIRECT CURRENT AND ALTERNATING CURRENT

The current derived from a cell or a battery is direct current (d.c.) - since it is unidirectional. The positive and negative terminals of d.c sources have fixed polarity, therefore, level of d.c remains constant with time (Fig.14.14). On the contrary, there is also a current which changes its polarity again and again.

Such a current that changes direction after equal intervals of time is called alternating current or a.c (Fig.14.15). This type of current is produced by AC generators.

Self Assessment

A light bulb is switched on for 40 s. If the electrical energy consumed by the bulb during this time is 2400 J, find the power of the bulb.

Remember

- To work out the energy transferred, the time must be in seconds and the power in watts.
- To work out the cost, the power must be in kilowatts and the time must be in hours.

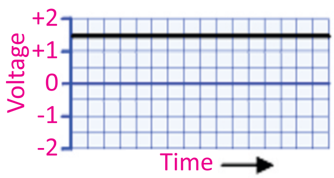


Fig.14.14: variation of voltage with time.

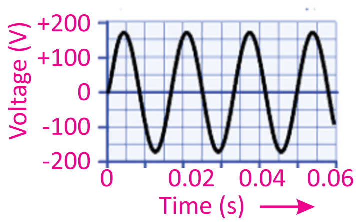


Fig. 14.15: Variation of voltage with time.

The time interval after which the a.c voltage or current repeats its value is known as its time period.

The change in the values of voltage and current corresponds to the frequency of the source. In Pakistan, alternating current oscillates 50 times every second. Thus, its frequency is 50 Hz Alternating current has advantages that make it more practical for use in transferring electrical energy. For this reason, the current supplied to our homes by power companies is alternating current rather than direct current.

Colour coding

Livewire (*L*): Red or brown
Neutralwire (*N*): Black or blue
Earthwire (*E*): Green/yellow

Supply to a House

The electric power enters our house through three wires. One is called **earthwire or ground wire (*E*)**. This carries no electricity. The earthwire is connected to a large metal plate buried deep in the ground near the house. The other wire is maintained at zero potential by connecting it to the Earth at the power station itself and is called **neutral wire (*N*)**. This wire provides the return path for the current. The third wire is at a high potential and is called **livewire (*L*)**. The potential difference between the livewire and the neutral wire is 220V.

Our body is a good conductor of electricity through which current can easily pass. Therefore, if a person holds livewire, current will start flowing to the ground while passing through his body which may prove fatal for the person. All electrical appliances are connected across the neutral and the livewires. The same potential difference is therefore applied to all of them and hence these are connected in parallel to the power source.

Effect of electric currents on the body

Current	Effect
0.001 A	Can be felt
0.005 A	Is painful
0.010 A	Causes involuntary muscle contractions (spasms)
0.015 A	Causes loss of muscle control
0.070 A	Goes through the heart; causes serious disruption; probably fatal if current lasts for more than 1 s.

House Wiring

Figure 14.16 shows the system of house wiring. The wires coming from the mains are connected to electricity meter installed in the house. The output power from the electric meter is taken to the main distribution board and then to the domestic electric circuit.

The main box contains fuses of rating about 30 A. A

separate connection is taken from the livewire of each appliance. The terminal of the appliance is connected to the livewire through a separate fuse and a switch. If the fuse of one appliance burns out, it does not affect the other appliances.

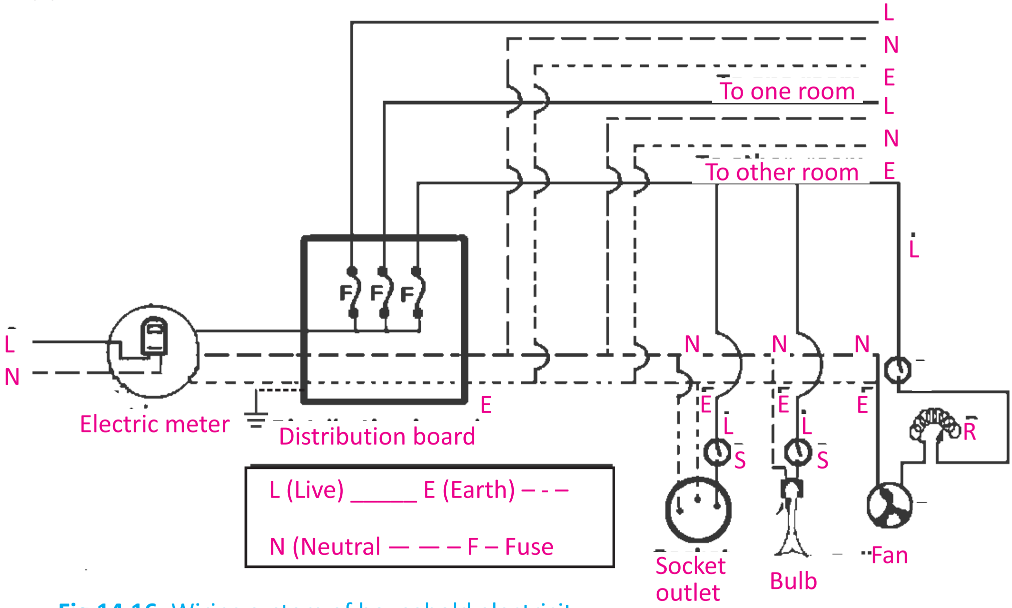


Fig.14.16: Wiring system of household electricity

In house wiring, all appliances are connected in parallel with each other. This means they all get the full mains voltage and one can turn ON any appliance without having to turn ON another.

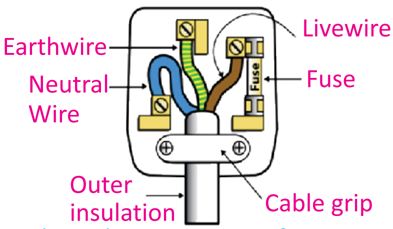
14.13 HAZARDS OF ELECTRICITY

While electricity has become part and parcel of our lives, care should be taken to save ourselves from its hazardous effects. Voltage of 50 V and current of 50 mA can be fatal. Major dangers of electricity are electric shock and fire. Here we discuss some faults in electrical circuits that may cause electricity hazards.

Insulation Damage

All electrical wires are well insulated with some plastic cover for the purpose of safety. But when electrical current exceeds the rated current carrying capacity of the conductor, it can produce excess current that can damage insulation due to overheating of cables. This results into a short circuit which

For your information



This is the correct way of wiring of a three pin main plug. Put everything in proper place. Fuse is placed for safety purpose. In case of excess current, it will burn out and will break the circuit.

can severely damage electrical devices or persons.

A short circuit occurs when a circuit with a very low resistance is formed. The low resistance causes the current to be very large. When appliances are connected in parallel, each additional appliance placed in circuit reduces the equivalent resistance in the circuit and increases the current through the wires. This additional current might produce enough thermal energy to melt the wiring's insulation which causes a short circuit, or even starts a fire.

Short circuit can also occur when the livewire and the neutral wires come in direct contact (Fig.14.17).

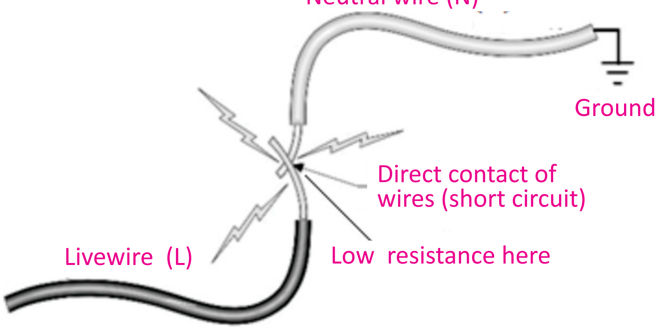


Fig. 14.17: Short circuit

In order to avoid such situations, the wires carrying electricity should never be naked. Rather they should be covered with good insulator. Such an insulation covered wire is called cable. Constant friction may also remove the insulation from the wire whereas too much moisture also damages the insulation. In such a situation, it is advisable to use a cable with two layers of insulation.

Damp Conditions

Dry human skin has a resistance of 100, 000 ohms or more! But under damp conditions (wet environment) resistance of human skin is reduced drastically to few hundred ohms. Therefore, never operate any electrical appliance with wet hands. Also keep switches, plugs, sockets and wires dry.

Precautionary Symbols

Do not expose to water

Do not use electrical equipment near inflameable materials

For your information

Do not fly kites near electricity lines. It may cause some fatal accident.

14.14 SAFE USE OF ELECTRICITY IN HOMES

In order to protect persons, devices and property from the hazards of electricity there is a need of extensive safety measures in household electricity. Take much care to use fuses and circuit breakers in an electric circuit as safety devices. They prevent circuit overloads that can occur when too many appliances are turned ON at the same time or when a short circuit occurs in one appliance.

Fuse

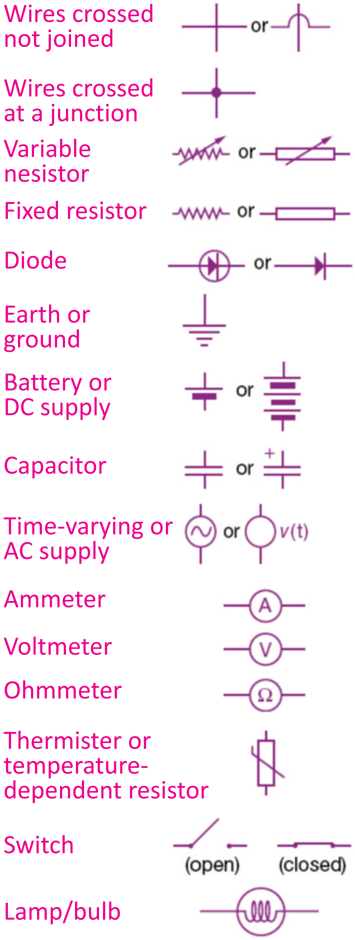
A fuse is a safety device that is connected in series with the livewire in the circuit to protect the equipments when excess current flows. It is short and thin piece of metal wire that melts when large current passes through it. If a large, unsafe current passes through the circuit, the fuse melts and breaks the circuit before the wires become very hot and cause fire. Fuses are normally rated as 5 A, 10 A, 13 A,30 A, etc. Different types of fuses are shown in Fig.14.18.

Following safety measures should be taken while using fuses in household electrical circuits:

(i) Fuses to be used should have slightly more rating than the current which the electrical appliance will draw under normal conditions. For example, for a lightning circuit choose a 5 A fuse as the current drawn by each lamp is very small (about 0.4 A for a 100 W lamp). In such circuit, 10 lamps of 100 W can be safely used as the total current drawn is only 4 A which can be calculated using the formula $P = VI$.

Fig. 14 .18: Different types of fuses

Identifying Circuit Components



(ii) Fuses should be connected in the livewire so that the appliance will not operate after the fuse has blown.
(iii) Switch OFF the main before changing any fuse.

Fig. 14.19: Circuit Breaker

Circuit Breaker

The circuit breaker (Fig. 14.19) acts as a safety device in the same way as a fuse. It disconnects the supply automatically if current exceeds the normal value. When the normal current passes through the livewire the electromagnet is not strong enough to separate the contacts. If something goes wrong with the appliance and large current flows through the livewire, the electromagnet will attract the iron strip to separate the contacts and break the circuit (Fig. 14.20). The spring then keeps the contacts apart. After the fault is repaired, the contacts can then be pushed back together by pressing a button on the outside of the circuit breaker box.

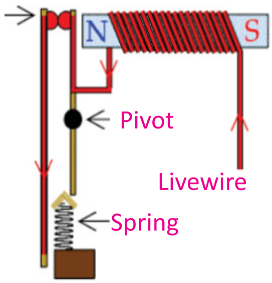


Fig. 14.20: Working principle of circuit breaker

Earthwire

Sometimes, even the fuse cannot capture the high currents coming from the livewire into the household appliance. Earthing further protects the user from electric shock by connecting the metal casing of the appliance to Earth (a wired connection to the bare ground). Many electrical appliances have metal cases, including cookers, washing machines and refrigerators. The Earthwire provides a safe route for the current to flow through, if the livewire touches the casing (Fig.14.21). We will get an electric shock if the livewire inside an appliance comes loose and touches the metal casing.

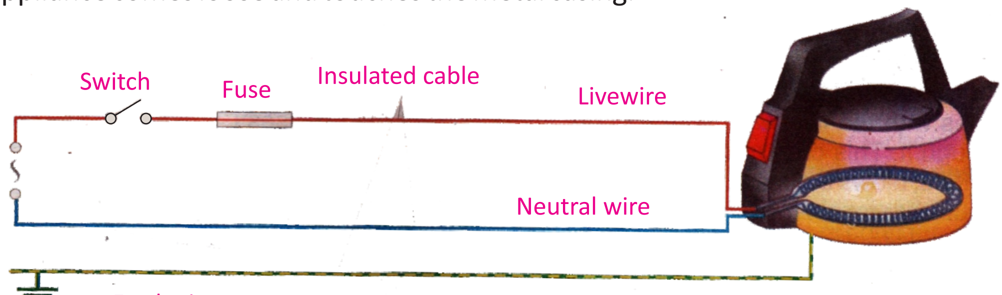


Fig. 14.21

However, the earth terminal is connected to the metal casing, so the current goes through the Earthwire instead of passing through our body and causing an electric shock. A strong current passes through the Earthwire because it has a very low resistance. This breaks the fuse and disconnects the appliance.

SUMMARY

- The time rate of flow of electric charge through any cross section is called electric current.
- The current due to flow of positive charge which is equivalent to current due to flow of negative charge in opposite direction is known as conventional current.
- Ampere is the SI unit of current.
- e.m.f. is the total amount of energy supplied by the battery or the cell in moving a one coulomb of positive charge from the -ve to the +ve terminal of the battery.
- Ohm's law states that the current I passing through a conductor is directly proportional to the potential difference V applied across its ends provided the temperature and physical state of the conductor do not change.
- Resistance R is a measure of opposition to the flow of current through a conductor. Its SI unit is ohm. It is denoted by the symbol Ω. When a potential difference of one volt is applied across the ends of a conductor and one ampere of current passes through it, then its resistance will be one ohm.
- Materials in which electrons can freely move so as to pass electricity are called conductors while in insulators no free electrons are available for the conduction of electricity.
- The equivalent resistance R_e of a series combination of '*n*' resistances is given by

$$R_e = R_1 + R_2 + R_3 + \ldots\ldots + R_n$$

- The equivalent resistance R_e of a parallel combination of '*n*' resistances is given by

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots + \frac{1}{R_n}$$

- Galvanometer is a sensitive instrument which detects current in a circuit. It is always connected in series with the circuit.
- Ammeter is an electrical instrument which measures larger current. It is always connected in series in a circuit.
- Voltmeter is an electrical instrument used to measure potential difference between two points in a circuit. It is always connected parallel to a circuit component.

- The amount of heat energy generated in a resistance due to flow of electric current is equal to the product of the square of current, resistance and the time interval ($W = I^2Rt$). This is called Joule's law.
- kilowatt-hour is the amount of energy obtained from a source of one kilowatt in one hour. It is equal to 3.6 mega joule.
- The current which does not change its direction of flow is known as direct current or d.c.
- The current which changes its direction of flow after regular intervals of time is known as alternating current or a.c.

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the following choices:

i. An electric current in conductors is due to the flow of
(a) positive ions (b) negative ions
(c) positive charges (d) free electrons

ii. What is the voltage across a 6 Ω resistor when 3 A of current passes through it?
(a) 2 V (b) 9 V
(c) 18 V (d) 36 V

iii. What happens to the intensity or the brightness of the lamps connected in series as more and more lamps are added?
(a) increases (b) decreases
(c) remains the same (d) cannot be predicted

iv. Why should household appliances be connected in parallel with the voltage source?
(a) to increase the resistance of the circuit
(b) to decrease the resistance of the circuit
(c) to provide each appliance the same voltage as the power source
(d) to provide each appliance the same current as the power source

v. Electric potential and e.m.f
(a) are the same terms (b) are the different terms
(c) have different units (d) both (b) and (c)

vi. When we double the voltage in a simple electric circuit, we double the
(a) current (b) power
(c) resistance (d) both (a) and (b)

vii. If we double both the current and the voltage in a circuit while keeping its resistance constant, the power
(a) remains unchanged (b) halves
(c) doubles (d) quadruples

viii. What is the power rating of a lamp connected to a 12 V source when it carries 2.5 A?

(a) 4.8 W (b) 14.5 W
(c) 30 W (d) 60 W

ix. The combined resistance of two identical resistors, connected in series is 8 Ω. Their combined resistance in a parallel arrangement will be

(a) 2 Ω (b) 4 Ω
(c) 8 Ω (d) 12 Ω

REVIEW QUESTIONS

14.1. Define and explain the term electric current.
14.2. What is the difference between electronic current and conventional current?
14.3. What do we mean by the term e.m.f? Is it really a force? Explain.
14.4. How can we differentiate between e.m.f. and potential difference?
14.5. Explain Ohm's law. What are its limitations?
14.6. Define resistance and its units.
14.7. What is the difference between conductors and insulators?
14.8. Explain the energy dissipation in a resistance. What is Joule's law?
14.9. What is difference between D.C and A.C?
14.10. Discuss the main features of parallel combination of resistors.
14.11. Determine the equivalent resistance of series combination of resistors.
14.12. Describe briefly the hazards of household electricity.
14.13. Describe four safety measures that should be taken in connection with the household circuit.
14.14. Design a circuit diagram for a study room that needs the following equipments in parallel:

(a) One 100 W lamp operated by one switch.
(b) One reading lamp fitted with a 40 W bulb which can be switched ON and OFF from two points.
(c) What is the advantage of connecting the equipments in parallel instead of series?

CONCEPTUAL QUESTIONS

14.1. Why in conductors charge is transferred by free electrons rather than by positive charges?
14.2. What is the difference between a cell and a battery?
14.3. Can current flow in a circuit without potential difference?
14.4. Two points on an object are at different electric potentials. Does charge necessarily flow between them?
14.5. In order to measure current in a circuit why ammeter is always connected in series?
14.6. In order to measure voltage in a circuit voltmeter is always connected in parallel. Discuss.

14.7. How many watt-hours are there in 1000 joules?

14.8. From your experience in watching cars on the roads at night, are automobile headlamps connected in series or in parallel.

14.9. A certain flash-light can use a 10 ohm bulb or a 5 ohm bulb. Which bulb should be used to get the brighter light? Which bulb will discharge the battery first?

14.10. It is impracticable to connect an electric bulb and an electric heater in series. Why?

14.11. Does a fuse in a circuit control the potential difference or the current?

NUMERICAL PROBLEMS

14.1. A current of 3 mA is flowing through a wire for 1 minute. What is the charge flowing through the wire? **Ans. (180×10^{-3} C)**

14.2. At 100,000 Ω, how much current flows through your body if you touch the terminals of a 12 V battery? If your skin is wet, so that your resistance is only 1000 Ω, how much current would you receive from the same battery? **Ans.(1.2×10^{-4} A, 1.2×10^{-2} A)**

14.3. The resistance of a conductor wire is 10 MΩ. If a potential difference of 100 volts is applied across its ends, then find the value of current passing through it in mA.

Ans. (0.01 mA)

14.4. By applying a potential difference of 10 V across a conductor, a current of 1.5 A passes through it. How much energy would be obtained from the current in 2 minutes?

Ans.(1800 J)

14.5. Two resistances of 2 kΩ and 8 kΩ are joined in series, if a 10 V battery is connected across the ends of this combination, find the following quantities:

(a) The equivalent resistance of the series combination.

(b) Current passing through each of the resistances.

(c) The potential difference across each resistance.

Ans. [(a) 10 kΩ (b) 1 mA (c) 2 V, 8 V]

14.6. Two resistances of 6 kΩ and 12 kΩ are connected in parallel. A 6 V battery is connected across its ends, find the values of the following quantities:

(a) Equivalent resistance of the parallel combination.

(b) Current passing through each of the resistances.

(c) Potential difference across each of the resistance.

Ans. [(a) 4 kΩ, (b) 1 mA,0.5 mA (c) 6 V]

14.7. An electric bulb is marked with 220 V, 100 W. Find the resistance of the filament of the bulb. If the bulb is used 5 hours daily, find the energy in kilowatt-hour consumed by the bulb in one month (30 days). **Ans. (484 Ω, 15 kWh)**

14.8. An incandescent light bulb with an operating resistance of 95 Ω is labelled "150 W."

Is this bulb designed for use in a 120 V circuit or a 220 V circuit?

Ans. (It has been designed for 120 V)

14.9. A house is installed with

(a) 10 bulbs of 60 W each of which are used 5 hours daily.

(b) 4 fans of 75 W each of which run 10 hours daily.

(c) One T.V. of 100 W which is used for 5 hours daily.

(d) One electric iron of 1000 W which is used for 2 hours daily.

If the cost of one unit of electricity is Rs.4. Find the monthly expenditure of electricity (one month =30 days). **Ans. (Rs. 1020/-)**

14.10. A 100 W lamp bulb and a 4 kW water heater are connected to a 250 V supply. Calculate (a) the current which flows in each appliance (b) the resistance of each appliance when in use. **Ans. [(a) 0.4 A, 16 A (b) 625 Ω, 15.62 Ω]**

14.11. A resistor of resistance 5.6 Ω is connected across a battery of 3.0 V by means of a wire of negligible resistance. A current of 0.5 A passes through the resistor. Calculate

(a) Power dissipated in the resistor.

(b) Total power produced by the battery.

(c) Give the reason of difference between these two quantities.

Ans. [(a) 1.4 W (b) 1.5 W

(c) some power is lost by the internal resistance of the battery]

Unit 15
ELECTROMAGNETISM

After studying this unit, students will be able to:

- explain by describing an experiment that an electric current in a conductor produces a magnetic field around it.
- describe that a force acts on a current-carrying conductor placed in a magnetic field as long as the conductor is not parallel to the magnetic field.
- state that a current-carrying coil in a magnetic field experiences a torque.
- relate the turning effect on a coil to the action of a D.C. motor.
- describe an experiment to show that a changing magnetic field can induce e.m.f. in a circuit.
- list factors affecting the magnitude of an induced e.m.f.
- explain that the direction of an induced e.m.f opposes the change causing it and relate this phenomenon to conservation of energy .
- describe a simple form of A.C. generator.
- describe mutual induction and state its units.
- describe the purpose of transformers in A.C. circuits.
- identify that a transformer works on the principle of mutual induction between two coils.

Science, Technology and Society Connections

The students will be able to:

- describe the application of the magnetic effect of an electric current in relay, door latch, loudspeaker, and circuit breaker.
- identify the role of transformers in power transmission from power station to your house.
- list the use of transformer (step-up and step-down) for various purposes in your home.
- discuss and enlist the advantage of high voltage power transmission.

Electromagnetism is the study of magnetic effects of current. The use of electromagnetism in different fields of science and technology is very wide. Motors and electric meters are based on the effect of magnetism produced by the electric current in wires. Generators produce electric current due to the movement of wires near very large magnets.

Interesting information

Electric charges can be separated into a single type. For example, you can have a single negative charge or a single positive charge. Magnetic poles cannot be separated. It is not possible to have a magnetic north pole without a magnetic south pole. This is a fundamental difference between magnetism and electricity.

15.1 MAGNETIC EFFECTS OF A STEADY CURRENT

Ampere discovered that when a current passes through a conductor, it produces magnetic field around it. To demonstrate this, we take a straight conductor wire and pass it vertically through a cardboard (Fig.15.1-a). Now connect the two ends of the conductor wire with the terminals of the battery so that current flows through the circuit in the clockwise direction. The lines of force of the magnetic field produced around the wire would be in the form of concentric circles. If we place a compass needle at different points in the region of magnetic field, it will align along the direction of magnetic field. Also if we sprinkle some iron filings on the cardboard around the wire, they will align themselves in concentric circles in the clockwise direction.

For your information

Weak ionic current in our body that travels along the nerve can produce the magnetic effect. This forms the basis of obtaining images of different parts of body. This is done using the technique called Magnetic Resonance Imaging (MRI). Heart and brain are two main organs where significant magnetic fields can be produced. Using MRI doctors can diagnose the disorders of brain and heart etc.

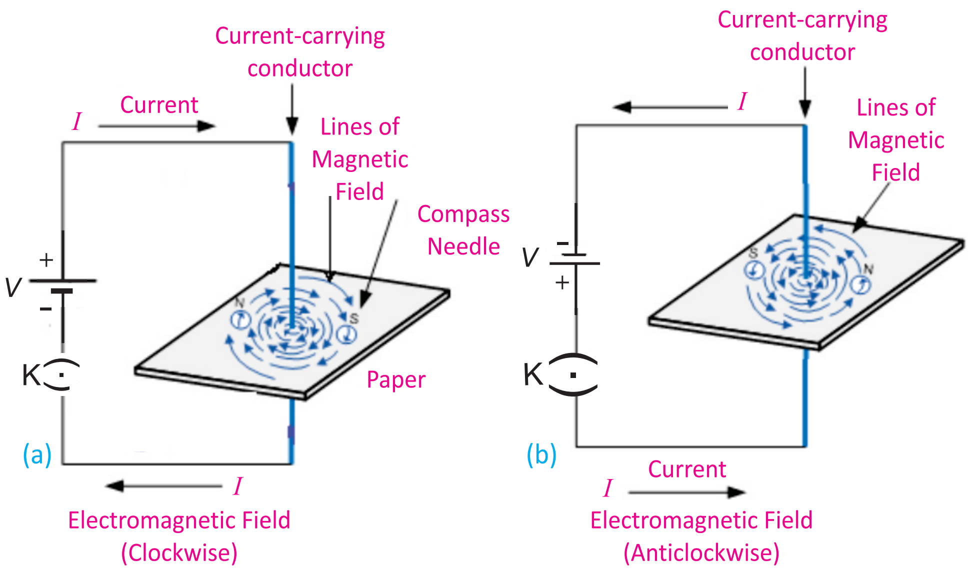


Fig. 15.1

If we reverse the direction of the current by reversing the terminals of the battery, the compass needle also reverses its direction. Now the magnetic field lines will align in the anticlockwise direction (Fig.15.1-b). The magnetic field produced is stronger near the current-carrying conductor and weaker farther away from it.

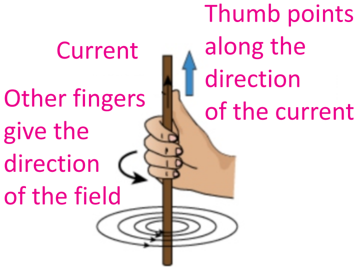


Fig.15.2: Right hand grip rule

Direction of magnetic field

The direction of the magnetic field is governed by the direction of the current flowing through the conductor. A simple method of finding the direction of magnetic field around the conductor is the Right Hand Grip Rule.

Grasp a wire with your right hand such that your thumb is pointed in the direction of current. Then curling fingers of your hand will point in the direction of the magnetic field.

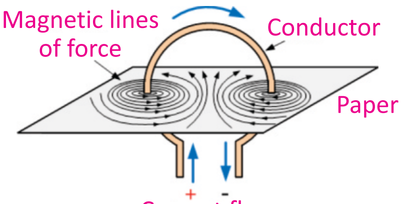


Fig.15.3

Activity 15.1: Take a straight piece of wire and bend it in the form of a single loop. Now pass it through a cardboard having two holes. Connect the ends of loop to a battery so that a current starts flowing through it (Fig.15.3). Now sprinkle some iron filings on the cardboard. Note the pattern of the iron filings formed on the cardboard. Do the magnetic field lines between the two parts of the loop resemble to that of the bar magnet?

Magnetic field of a solenoid

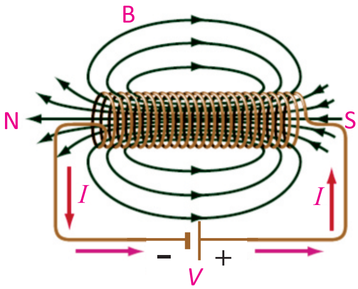


Fig. 15.4: Magnetic field due to a solenoid

A coil of wire consisting of many loops is called a solenoid (Fig.15.4). The field from each loop in a solenoid adds to the fields of the other loops and creates greater total field strength. Electric current in the solenoid of wire produces magnetic field which is similar to the magnetic field of a permanent bar magnet. When this current-carrying solenoid is brought close to a suspended bar magnet, one end of the solenoid repels the north pole of the bar magnet. Thus, the current-

carrying solenoid has a north and a south pole and behaves like a magnet.

The type of temporary magnet, which is created when current flows through a coil, is called an electromagnet.

The direction of the field produced by a coil due to the flow of conventional current can be found with the help of right hand grip rule (Fig.15.5) stated as

If we grip the coil with our right hand by curling our fingers in the direction of the conventional current, our thumb will indicate the north pole of the coil.

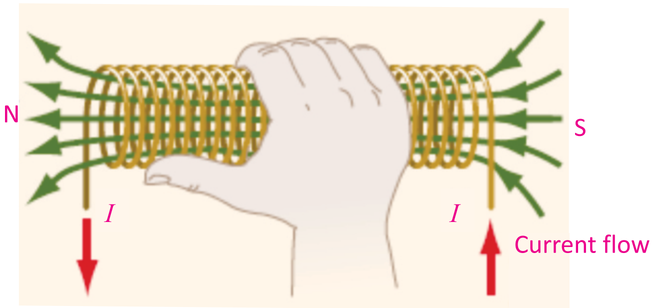


Fig. 15.5: Right hand grip rule for a coil

15.2 FORCE ON A CURRENT-CARRYING CONDUCTOR PLACED IN A MAGNETIC FIELD

We know that electric current produces a magnetic field similar to that of a permanent magnet. Since a magnetic field exerts force on a permanent magnet, it implies that current-carrying wire should also experience a force when placed in a magnetic field.

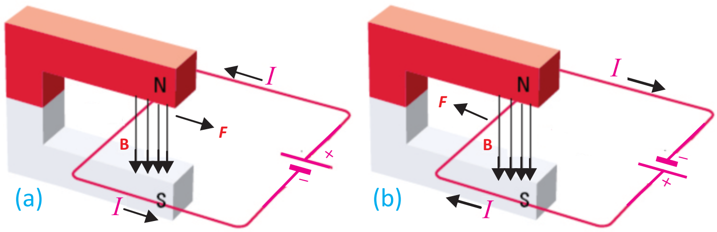
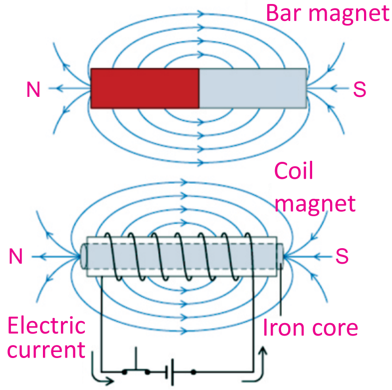


Fig. 15.6: Force on a current-carrying wire in magnetic field

For your information



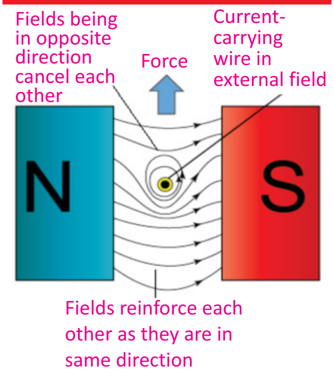
Similarity between magnetic fields of a bar magnet and that of a coil.

The force on a wire in a magnetic field can be demonstrated using the arrangement shown in Fig. 15.6. A battery produces current in a wire placed inside the magnetic field of a permanent magnet. Current-carrying wire produces its own magnetic field which interacts with the field of the magnet. As a result, a force is exerted on the wire. Depending on the direction of the current, the force on the wire either pushes or pulls it towards right (Fig. 15.6-a) or towards left (Fig.15.6-b).

Michael Faraday discovered that the force on the wire is at right angles to both the direction of the magnetic field and the direction of the current. The force is increased if

- The current in the wire is increased
- Strength of magnetic field is increased
- The length of the wire inside the magnetic field is increased

For your information



Determining the direction of force

Faraday's description of the force on a current-carrying wire does not completely specify the direction of force because the force can be towards left or towards right. The direction of the force on a current-carrying wire in a magnetic field can be found by using Fleming's left hand rule stated as:

Stretch the thumb, forefinger and the middle finger of the left hand mutually perpendicular to each other. If the forefinger points in the direction of the magnetic field, the middle finger in the direction of the current, then the thumb would indicate the direction of the force acting on the conductor.

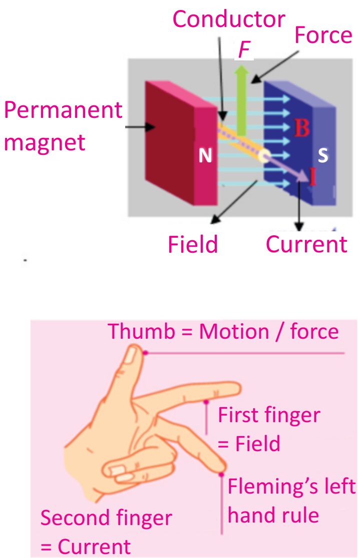


Fig. 15.7: Direction of force on a current-carrying conductor placed in a magnetic field

As shown in Fig. 15.7, the force acting on the conductor is at right angles to both the directions of current and magnetic field according to Fleming's left hand rule.

15.3 TURNING EFFECT ON A CURRENT-CARRYING COIL IN A MAGNETIC FILED

If instead of a straight conductor, we place a current-carrying loop inside the magnetic field, the loop will rotate due to the torque acting on the coil. This is also the working principle of electric motors. Consider a rectangular coil of wire with sides PQ and RS, lying perpendicular to the field, placed between the two poles of a permanent magnet (Fig. 15.8). Now if the ends of the coil are connected with the positive and negative terminals of a battery, a current would start flowing through the coil. The current passing through the loop enters from one end of the loop and leaves from the other end.

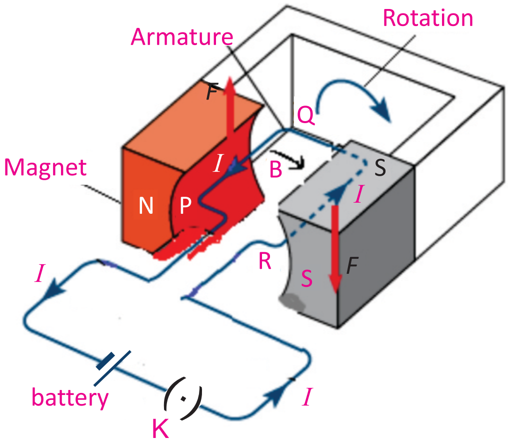


Fig. 15.8: A current-carrying coil in a magnetic field

Now apply Fleming's left hand rule to each side of the coil (Fig. 15.8). We can see that on PQ side of the loop force acts upward, while on the RS side of the loop force acts downward. It is because the direction of the current through the two sides of the loop facing the two poles is at right angles to the field but opposite to each other. The two forces which are equal in magnitude but opposite in direction form a couple. The resulting torque due to this couple rotates the loop, and the magnitude of the torque acting on the loop is proportional to the magnitude of the current passing through the loop. If we increase the number of loops, the turning effect is also increased. This is the working principle of electric motors.

Activity

Suppose direction of current passing through two straight wires is same. Draw the pattern of magnetic field of current due to each wire. Would the wires attract or repel each other?

15.4 D. C. MOTOR

We can see from Fig. 15.9 that the simple coil placed in a magnet cannot rotate more than 90°. The forces push the PQ side of the coil up and the RS side of the loop down until the loop reaches the vertical position. In this situation, plane of the loop is perpendicular to the magnetic field and the net force on the coil is zero. So the loop will not continue to turn because the forces are still up and down and hence balanced.

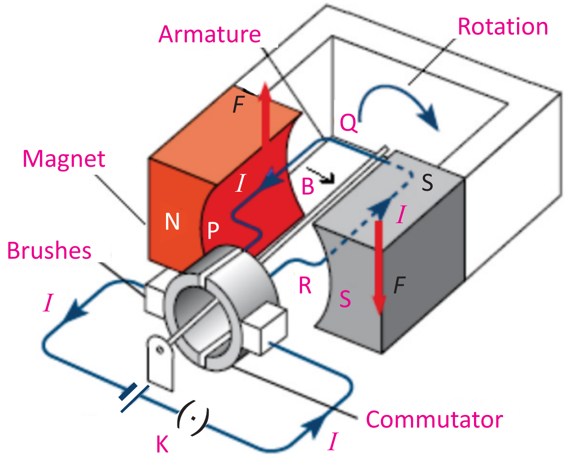


Fig. 15.9: Working principle of D.C motor

How can we make this coil to rotate continuously? It can be done by reversing the direction of the current just as the coil reaches its vertical position. This reversal of current will allow the coil to rotate continuously**.** To reverse direction of current, the connection to coil is made through an arrangement of brushes and a ring that is split into two halves, called a split ring commutator (Fig. 15.9). Brushes, which are usually pieces of graphite, make contact with the commutator and allow current to flow into the loop. As the loop rotates, so does the commutator. The split ring is arranged so that each half of the commutator changes brushes just as the coil reaches the vertical position. Changing brushes reverse the current in the loop.

As a result, the direction of the force on each side of the coil is reversed and it continues to rotate. This process repeats at each half-turn, causing coil to rotate in the magnetic field continuously. The result is an **electric**

Do you know?

Bank credit cards have a magnet strips engraved on them. On this strip account information of the user are stored which are read by the ATM machine.

motor, which is a device that converts electric energy into rotational kinetic energy.

In a practical electric motor, the coil, called the **armature,** is made of many loops mounted on a shaft or axle. The magnetic field is produced either by permanent magnets or by an electromagnet, called a field coil. The torque on the armature, and, as a result, the speed of the motor, is controlled by varying the current through the motor.
The total force acting on the armature can be increased by

- Increasing the number of turns of the coil
- Increasing the current in the coil
- Increasing the strength of the magnetic field
- Increasing the area of the coil

CONNECTION:
Magnetic field lines help us to visualize the magnitude and direction of the magnetic field vectors, just as electric field lines do for the magnitude and direction of **E.**

15.5 ELECTROMAGNETIC INDUCTION

Hans Christian Oersted and Ampere discovered that an electric current through a conductor produces a magnetic field around it. Michael Faraday thought that the reverse must also be true; that a magnetic field must produce an electric current. Faraday found that he could induce electric current by moving a wire through a magnetic field. In the same year, Joseph Henry also showed that a changing magnetic field could produce electric current. Now we shall discuss Faraday's experiments for the production of e.m.f. in magnetic field.
The strength of magnetic field is defined as the number of magnetic lines of force passing through any surface. The number of lines of force is maximum when the surface is held perpendicular to the magnetic lines of force (Fig.15.10). It will be minimum when surface is held parallel to the magnetic lines of force (Fig.15.11). If we place a coil in the magnetic field of a bar magnet, some of the magnetic lines of force will pass through it. If the coil is far away from the magnet, only a few lines of force will pass through the coil (Fig.15.12-a). However, if the coil is close to the magnet, a large number of lines of force will pass through it (Fig.15.12-b).

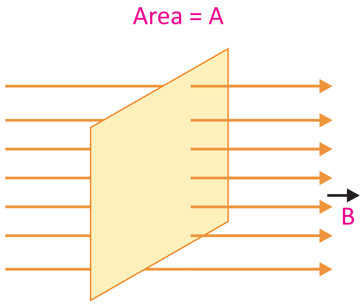


Fig.15.10: Maximum strength of magnetic field

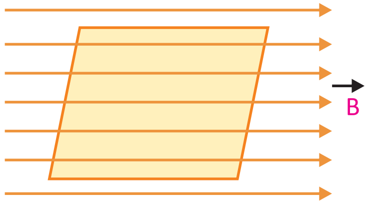


Fig 15.11: Minimum strength of magnetic field

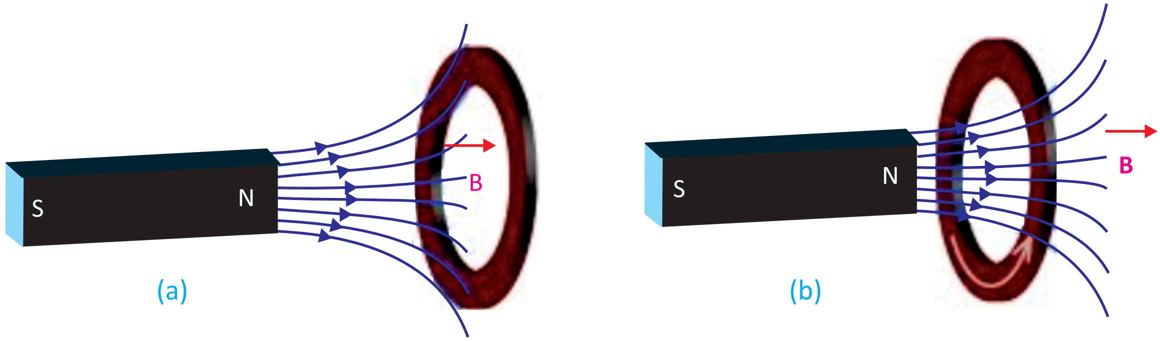


Fig. 15.12: Variation of magnetic field lines of force through a coil placed at different distances from the magnet

This means, we can change the number of magnetic lines of force through a coil by moving it in the magnetic field. This change in the number of magnetic field lines will induce an e.m.f. in the coil. This is the basic principle of the production of electricity.

Activity 15.2: Take a rectangular loop of wire and connect its two ends with a galvanometer. Now hold the wire stationary or move it parallel to the magnetic field of a strong U-shaped magnet. Galvanometer shows no deflection and hence there is no current. Now move the wire downward through the field, current is induced in one direction as shown by the deflection of the galvanometer (Fig. 15.13-a). Now move the wire upward through the field, current is induced in the opposite direction (Fig. 15.13-b).

Physics fact

It is said; Joseph Henry (1797–1878) had observed an induced current before Faraday, but Faraday published his results first and investigated the subject in more detail.

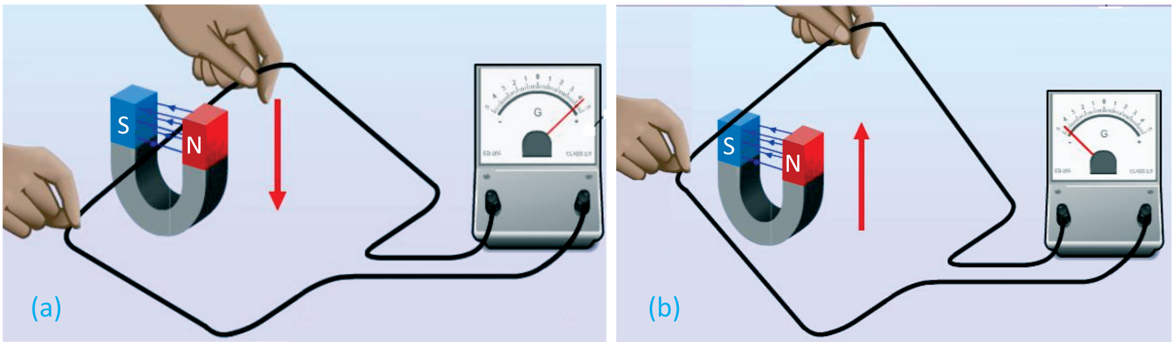


Fig. 15.13: Demonstration of electromagnetic induction by the movement of a wire loop in the magnet field

It implies that an electric current is generated in a wire only when the wire cuts magnetic field lines. This induced current is generated by the induced e.m.f. in the circuit. Faraday found that to generate current, either the

conductor must move through a magnetic field or a magnetic field must change across the conductor. Thus,

The process of generating an induced current in a circuit by changing the number of magnetic lines of force passing through it is called electromagnetic induction.

Activity 15.3: Fig. 15.14 shows one of Faraday's experiments in which current is induced by moving a magnet into the solenoid or out of the solenoid. When the magnet is stationary, no current is induced. When the magnet is moved towards the solenoid, the needle of galvanometer deflects towards right, indicating that a current is being induced in the solenoid (Fig.15.14-a). When the magnet is pulled away from the solenoid, the galvanometer deflects towards left, indicating that the induced current in the solenoid is in the opposite direction (Fig.15.14-b).

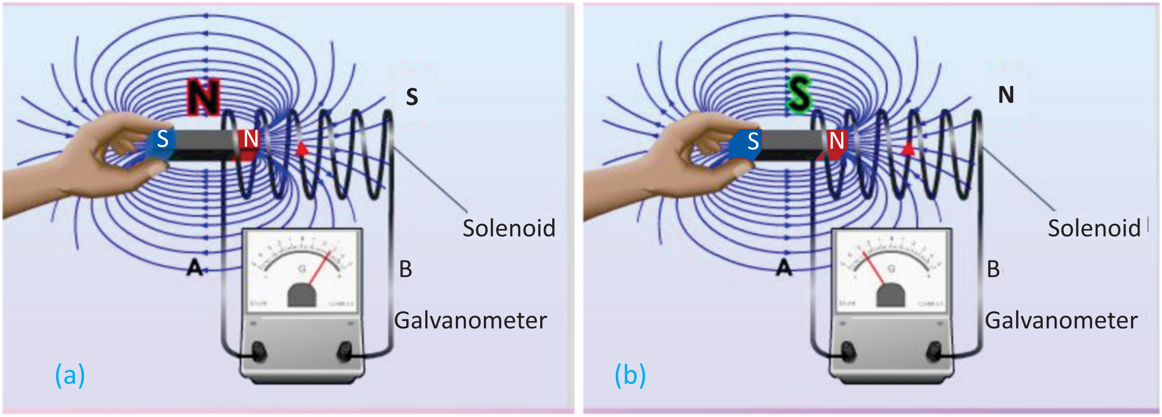


Fig. 15.14: Phenomenon of electromagnetic induction by the movement of a magnet through solenoid. (a) Magnet moves towards the stationary solenoid (b) Magnet moves away from the stationary solenoid

From the above experiments, we conclude that an e.m.f. is induced in the coil when there is a relative motion between the coil and the magnet. This phenomenon in which an e.m.f. is induced due to the relative motion between the coil and the magnet is called electromagnetic induction.

The value of induced e.m.f. in a circuit is directly proportional to the rate of change of number of magnetic lines of force through it.

This is called Faraday's law of electromagnetic induction.

Factors Affecting Induced e.m.f

The magnitude of induced e.m.f. in a circuit depends on the following factors:

1. Speed of relative motion of the coil and the magnet
2. Number of turns of the coil

15.6 Direction of induced e.m.f. – Lenz's Law

Lenz devised a rule to find out the direction of a current induced in a circuit. It is explained from the following activity:

Activity 15.4: If we bring a north pole of a bar magnet near a solenoid, an e.m.f. will be induced in the solenoid by electromagnetic induction (Fig. 15.15-a). The direction of the induced current in the solenoid by the induced e.m.f. will be such that it will repel the north pole of the magnet. This is only possible if the right end of the solenoid becomes a north pole. Hence, according to right hand grip rule, the direction of the induced current in the solenoid will be clockwise. Similarly, when we move the north pole of the magnet away from the solenoid, the direction of the induced current will be anticlockwise (Fig.15.15-b). In this case, left end of solenoid becomes south pole.

Direction of induced current

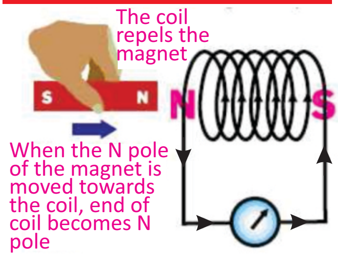


Fig.15.15 (a) Direction of induced current when magnet is moved towards the coil

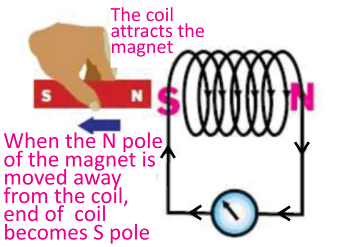


Fig.15.15 (b) Direction of induced current when magnet is moved away from the coil

The direction of an induced current in a circuit is always such that it opposes the cause that produces it.

If we apply the law of conservation of energy to electromagnetic induction, we realize that the electrical energy induced in a conductor comes from the kinetic energy of the moving magnet. We do some work on the magnet to bring it close to the solenoid. This work consequently appears as electrical energy in the conductor. Thus, mechanical energy of our hand used to push the magnet towards or away from the coil results into electrical energy. Hence, Lenz's law is a manifestation of the law of conservation of energy.

15.7 A.C. GENERATOR

If a coil is rotated in a magnetic field, a current will be induced

in the coil. The strength of this induced current depends upon the number of magnetic lines of force passing through the coil. The number of lines of magnetic force passing through the coil will be maximum when the plane of the coil is perpendicular to the lines of magnetic force. The number of lines of magnetic force will be zero when plane of the coil is parallel to the lines of force. Thus, when a coil rotates in a magnetic field, the induced current in it continuously changes from maximum to minimum value and from minimum to maximum value and so on. This is the basic principle on which an A.C generator works (Fig. 15.16).

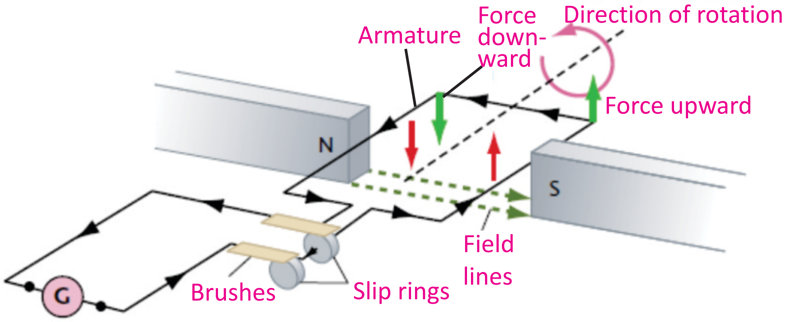


Fig. 15.16: A.C Generator

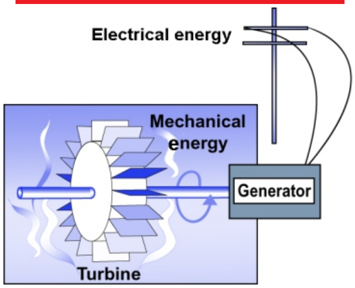
The armature is arranged so that it can rotate freely in the magnetic field. As the armature turns, the wire loops cut through the magnetic field lines and induced e.m.f. will be produced. The e.m.f. developed by the generator depends on the length of the wire rotating in the field. Increasing the number of loops in the armature, increases the wire length, thereby increasing the induced e.m.f

Current from a generator

When a generator is connected in a closed circuit, the induced *e.m.f.* generates an electric current. As the loop rotates, the strength and the direction of the current changes as shown in Fig. 15.17.

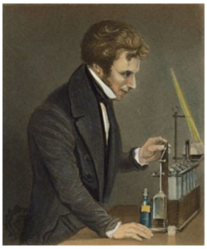
When the plane of will is perpendicular to field, the number of lines of magnetic force passing the trough it is maximum. Butt the change in the number of line through the coil is minimum. So e.m.f. induced is minimum.

Do you know?



A generator inside a hydroelectric dam uses electromagnetic induction to convert mechanical energy of a spinning turbine into electrical energy.

Michael Faraday (1791-1867)



Michael Faraday was a British chemist and physicist. At the early stage of his age, he had to work as a book binder to meet his financial needs. There he learnt a lot from the books that helped him to become an expert. Although Faraday received little formal education. He was one of the most influential scientists in history, and was one of the best experimentalist in the history of science. He discovered the principle of electromagnetic induction and the laws of electrolysis etc.

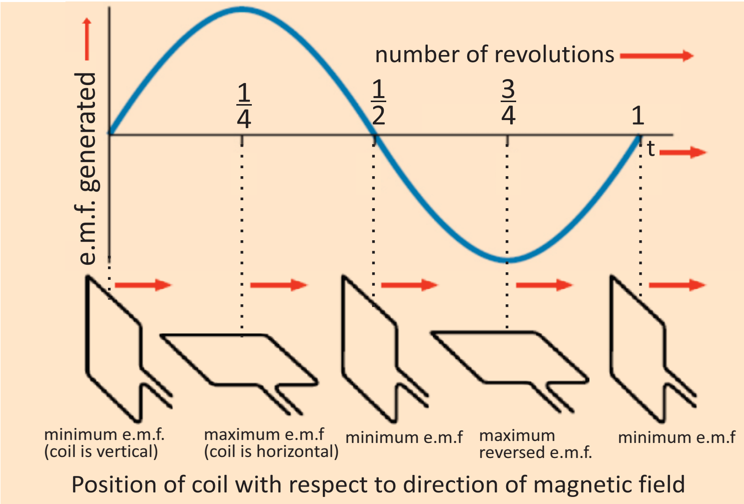


Fig. 15.17: e.m.f. Vs time for AC generator

The current is minimum when the plane of the loop is perpendicular to the magnetic field; that is, when the loop is in the vertical position. As the loop rotates from the vertical to the horizontal position, it cuts through larger magnetic field lines per unit of time, thus the e.m.f and the current increase. When the loop is in the horizontal position, the plane of the loop becomes parallel to the field, so the e.m.f and the current reaches its maximum value. As the loop continues to turn, the segment that was moving up begins to move down and reverses the direction of the e.m.f and the current in the loop. This change in direction takes place each time the loop turns through 180°. Thus, the e.m.f and the current change smoothly from zero to some maximum values and back to zero during each half-turn of the loop.

Connection:

A generator is a d.c motor with its input and output reversed.

For your information

Walk-through metal detectors are installed at airports and other places for security purpose. These detectors detect metal weapons etc. using the principle of electromagnetic induction.

15.8 MUTUAL INDUCTION

The phenomenon of production of induced current in one coil due to change of current in a neighboring coil is called mutual induction.

Suppose a system of two coils A and B placed close to each other (Fig.15.18). The coil A is connected to a battery and a switch, while a sensitive galvanometer is connected to the coil B. We observe that as soon as the switch of the coil A is closed, the galvanometer shows a momentary deflection.

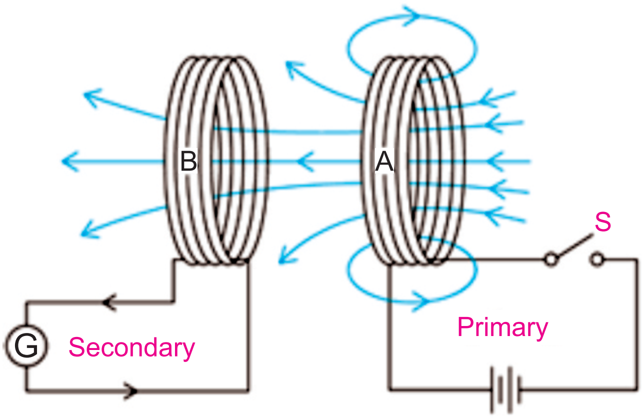
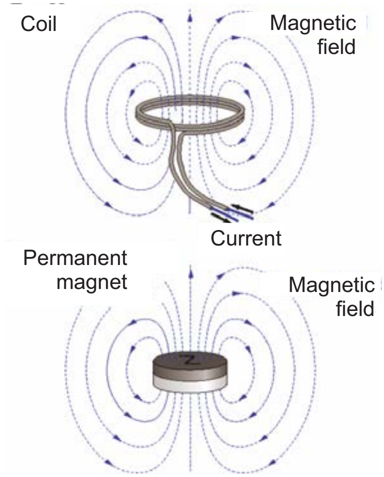


Fig.15.18: Mutual induction

Similarly, when the switch is opened, the galvanometer again shows a deflection but this time its direction is opposite to that of the previous case.

We can explain these observations using Faraday's law of electromagnetic induction. When the switch of coil A is closed, a current begins to flow in the coil due to which magnetic field is developed across the coil. Some of the magnetic lines of force of this field start passing through the coil B. Since current is changing in the coil A, hence number of magnetic lines of force across the coil B also changes due to which a current is induced in the coil B in accordance with Faraday's law. When current in the coil A becomes steady, number of magnetic lines of force across the coil A also becomes constant. Therefore, there is no more change in number of magnetic lines of force through the coil B due to which induced current in coil B reduces to zero.
Similarly, when the switch of the coil A is opened, the flow of current through it stops and its magnetic field reaches to zero. The number of magnetic lines of force through the coil B decreases to zero due to which current is again induced in it but in opposite direction to that in the previous case.

Do you know?



The magnetic field of a coil is identical to the field of a disk shaped permanent magnet.

15.9 TRANSFORMER

The transformer is a practical application of mutual induction. Transformers are used to increase or decrease AC

voltages. Usage of transformers is common because they change voltages with relatively little loss of energy. In fact, many of the devices in our homes, such as game systems, printers, and stereos use transformers for their working.

Working of a transformer

A transformer has two coils, electrically insulated from each other, but wound around the same iron core. One coil is called the primary coil. The other coil is called the secondary coil. Number of turns on the primary and the secondary coils are represented by N_P and N_S respectively.

When the primary coil is connected to a source of AC voltage, the changing current creates a changing magnetic field, which is carried through the core to the secondary coil. In the secondary coil, the changing field induces an alternating e.m.f.

The e.m.f. induced in the secondary coil, called the secondary voltage V_S, is proportional to the primary voltage V_P. The secondary voltage also depends on the ratio of the number of turns on the secondary coil to the number of turns on the primary coil, as shown by the following expression:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

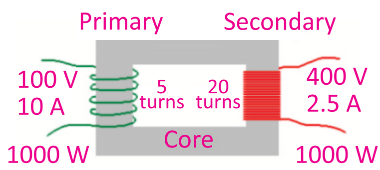


Fig. 15.19 (a) Step-up transformer

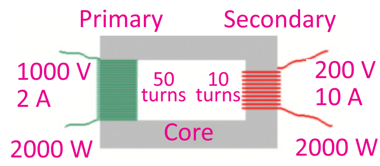


Fig. 15.19 (b) Step-down transformer

If the secondary voltage is larger than the primary voltage, the transformer is called a step-up transformer (Fig.15. 19-a). If the secondary voltage is smaller than the primary voltage, the transformer is called a step-down transformer (Fig.15. 19-b).

In an ideal transformer, the electric power delivered to the secondary circuit is equal to the power supplied to the primary circuit. An ideal transformer dissipates no power itself, and for such a transformer, we can write:

$$P_p = P_s$$
$$V_p I_p = V_s I_s$$

Example 15.1: If a transformer is used to supply voltage to a 12 V model train which draws a current of 0.8 A. Calculate the current in the primary if the voltage of the a.c. source is 240 V.

Solution: Given that, V_p= 240 V

$V_s = 12\text{ V}$

$I_s = 0.8\text{ A}$

$I_p = ?$

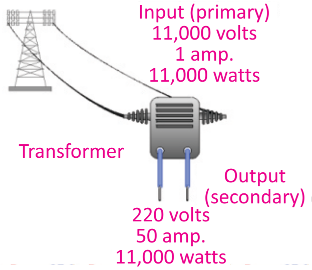
By law of conservation of energy,

Input power of the primary = Output power of the secondary

i.e., $I_p V_p = I_s V_s$

Therefore, $I_p = \frac{I_s V_s}{V_p}$ or $I_p = \frac{(12\text{ V})(0.8\text{ A})}{240\text{ V}} = 0.04\text{ A}$

Do you know?



A high power transformer can reduce the voltage keeping the power constant.

15.10 HIGH VOLTAGE TRANSMISSION

Electric power is usually generated at places which are far from the places where it is consumed. The power is transmitted over long distances at high voltage to minimize the loss of energy in the form of heat during transmission. As heat dissipated in the transmission cable of resistance R is I^2Rt. Hence, by reducing the current through the cable, power loss in the form of heat dissipation can also be reduced. So the alternating voltage is stepped up at the generating station.

It is then transmitted to the main sub-station. This voltage is stepped down and is transmitted to the switching transformer station or the city sub-station. At the city sub-station, it is further stepped down to 220 V and supplied to the consumers. A schematic diagram of high voltage transmission is shown in Fig. 15.20.

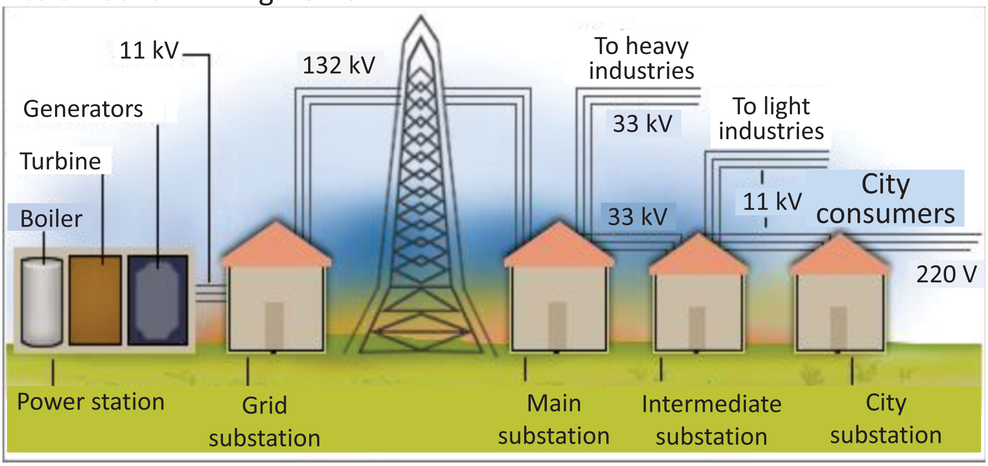


Fig.15.20: High voltage transmission

Transformers play an essential part in power distribution. Transformers work only with A.C. This is one reason why

mains power is supplied as an alternating current.

Applications of Electromagnet

Magnetic effect of current is called electromagnet. This effect is used in many devises like relay, electric bell, etc. Soft iron can easily be magnitized and demagnitized

RELAY

The relay is used to control a large current with the help of a small current. A relay is an electrical switch that opens and closes under the control of another electrical circuit (Fig. 15.21). The 1st circuit (input circuit) supplies current to the electromagnet. The electromagnet is magnetized and attracts one end of the iron armature. The armature then closes the contacts (2nd switch) and allows current to flow in the second circuit. When the 1st switch is opened again, the current to the electromagnet stops. Now electromagnet loses its magnetism and the 2nd switch is opened. Thus, the flow of current stops in the 2nd circuit. Some other examples of the magnetic effect of an electric current are loudspeaker, circuit breaker and door latches.

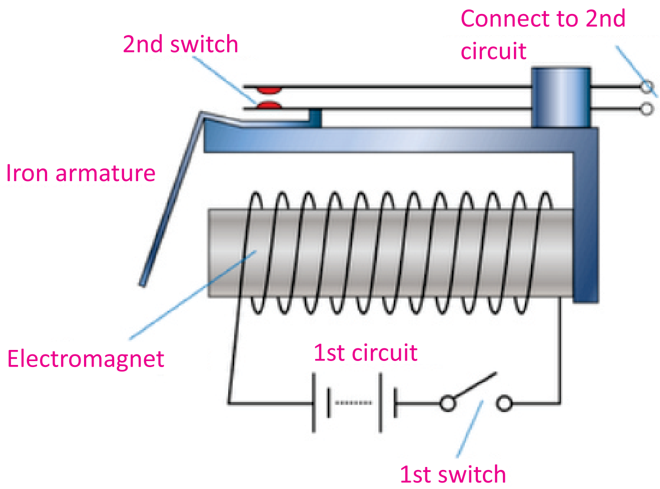


Fig. 15.21: Relay circuit

SUMMARY

- When electric current passes through a conductor, a magnetic field is set up in the space surrounding the conductor. In case of a straight current-carrying conductor, the lines of force are in the form of concentric circles.
- Direction of magnetic field around a current-carrying conductor can be found using right hand rule: "Grasp a wire with your right hand such that your thumb is pointed in the direction of the conventional (positive) current. Then curling fingers of your hand will point in the direction of the magnetic field".
- When a straight current-carrying conductor is placed perpendicularly in a magnetic field, it experiences a force in a direction at right angles to both the directions of the field and the current.
- When a current-carrying coil is placed in a magnetic field, it experiences a couple due to which the coil begins to rotate. A D.C motor operates on this principle. It converts electrical energy into mechanical energy.
- The number of magnetic lines of force passing through a certain surface is known as the magnetic field strength through that surface.
- When a magnetic field strength through a coil is changing, an e.m.f. is induced in it. The value of this induced e.m.f. is directly proportional to the rate of change of magnetic field strength.
- An A.C generator consists of a coil and a magnet. When this coil is made to rotate in a magnetic field, the magnetic field strength through it continuously changes due to which an alternating voltage is induced in it. Thus, A.C generator converts mechanical energy into electrical energy.
- If the change of current in a circuit induces a current in another circuit this phenomenon is known as mutual induction.
- Transformer is an electrical device which is used to increase or decrease the value of an alternating voltage. It works on the principle of mutual induction.

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the following choices:

i. Which statement is true about the magnetic poles?
   (a) unlike poles repel
   (b) like poles attract
   (c) magnetic poles do not effect each other
   (d) a single magnetic pole does not exist

ii. What is the direction of the magnetic field lines inside a bar magnet?
   (a) from north pole to south pole (b) from south pole to north pole
   (c) from side to side (d) there are no magnetic field lines

iii. The presence of a magnetic field can be detected by a
(a) small mass (b) stationary positive charge
(c) stationary negative charge (d) magnetic compass

iv. If the current in a wire which is placed perpendicular to a magnetic field increases, the force on the wire
(a) increases (b) decreases
(c) remains the same (d) will be zero

v. A D.C motor converts
(a) mechanical energy into electrical energy
(b) mechanical energy into chemical energy
(c) electrical energy into mechanical energy
(d) electrical energy into chemical energy

vi. Which part of a D.C motor reverses the direction of current through the coil every half-cycle?
(a) the armature (b) the commutator
(c) the brushes (d) the slip rings

vii. The direction of induced e.m.f. in a circuit is in accordance with conservation of
(a) mass (b) charge
(d) momentum (d) energy

viii. The step-up transformer
(a) increases the input current
(b) increases the input voltage
(c) has more turns in the primary
(d) has less turns in the secondary coil

ix. The turn ratios of a transformer is10. It means
(a) $I_s = 10\ I_p$ (b) $N_s = N_p/10$
(c) $N_s = 10\ N_p$ (d) $V_s = V_p/10$

REVIEW QUESTIONS

15.1. Demonstrate by an experiment that a magnetic field is produced around a straight current-carrying conductor.

15.2. State and explain the rule by which the direction of the lines of force of the magnetic field around a current-carrying conductor can be determined.

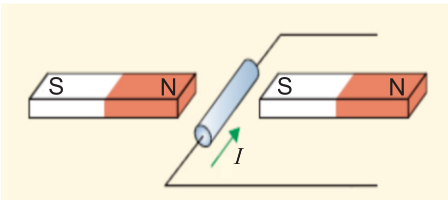
15.3. You are given an unmarked magnetized steel bar and bar magnet, its north and south ends are marked N and S respectively. State how would you determine the polarity at each end of the unmarked bar?

15.4. When a straight current-carrying conductor is placed in a magnetic field, it experiences a force. State the rule by which the direction of this force can be found out.

15.5. State that a current-carrying coil in a magnetic field experiences a torque.
15.6. What is an electric motor? Explain the working principle of D.C motor.
15.7. Describe a simple experiment to demonstrate that a changing magnetic field can induce e.m.f. in a circuit.
15.8. What are the factors which affect the magnitude of the e.m.f. induced in a circuit by a changing magnetic field?
15.9. Describe the direction of an induced e.m.f. in a circuit? How does this phenomenon relate to conservation of energy?
15.10. Draw a labelled diagram to illustrate the structure and working of A.C generator.
15.11. What do you understand by the term mutual induction?
15.12. What is a transformer? Explain the working of a transformer in connection with mutual induction.
15.13. The voltage chosen for the transmission of electrical power over large distances is many times greater than the voltage of the domestic supply. State two reasons why electrical power is transmitted at high voltage.
15.14. Why is the voltage used for the domestic supply much lower than the voltage at which the power is transmitted?

CONCEPTUAL QUESTIONS

15.1. Suppose someone handed you three similar iron bars and told you one was not magnet, but the other two were. How would you find the iron bar that was not magnet?
15.2. Suppose you have a coil of wire and a bar magnet. Describe how you could use them to generate an electric current.
15.3. Which device is used for converting electrical energy into mechanical energy?
15.4. Suppose we hang a loop of wire so that it can swing easily. If we now put a magnet into the coil, the coil will start swinging. Which way will it swing relative to the magnet, and why?
15.5. A conductor wire generates a voltage while moving through a magnetic field. In what direction should the wire be moved, relative to the field to generate the maximum voltage?
15.6. What is the difference between a generator and a motor?
15.7. What reverses the direction of electric current in the armature coil of D.C motor?
15.8. A wire lying perpendicular to an external magnetic field carries of a current in the direction shown in the diagram below. In what direction will the wire move due to the resulting magnetic force?



15.9. Can a transformer operate on direct current?

NUMERICAL PROBLEMS

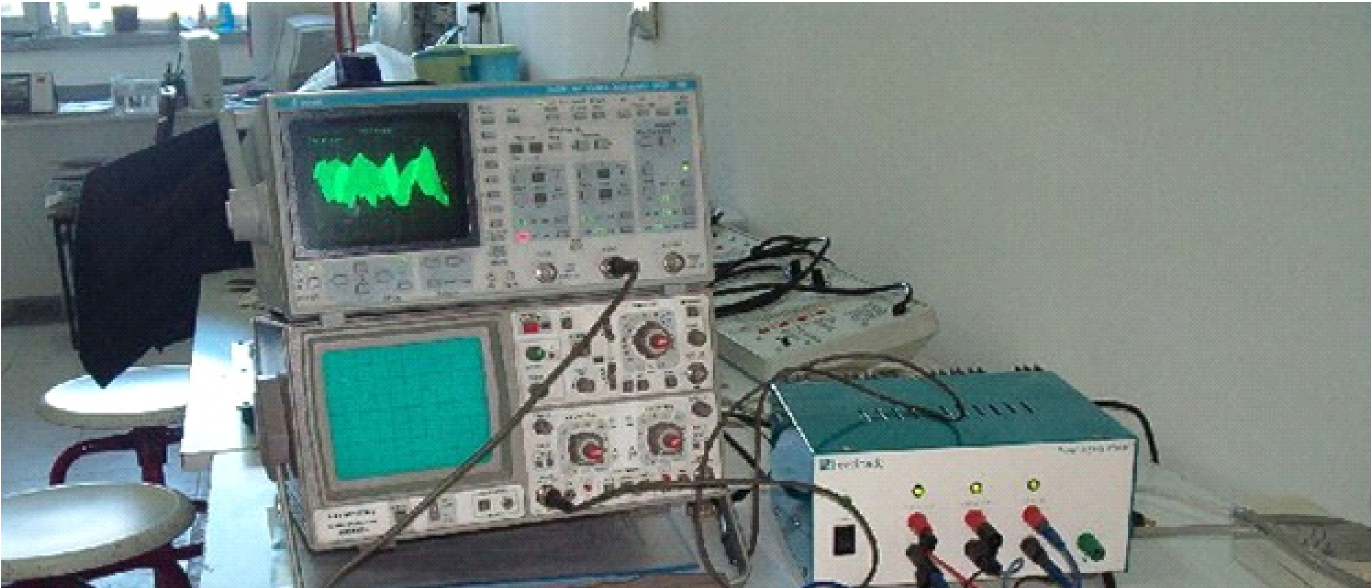
15.1. A transformer is needed to convert a mains 240 V supply into a 12 V supply. If there are 2000 turns on the primary coil, then find the number of turns on the secondary coil. **Ans. (100)**

15.2. A step-up transformer has a turn ratios of 1 : 100. An alternating supply of 20 V is connected across the primary coil. What is the secondary voltage? **Ans. (2000 V)**

15.3. A step-down transformer has a turns ratio of 100 : 1. An ac voltage of amplitude 170 V is applied to the primary. If the current in the primary is 1.0 mA, what is the current in the secondary? **Ans. (0.1A)**

15.4. A transformer, designed to convert the voltage from 240 V a.c mains to 12 V, has 4000 turns on the primary coil. How many turns should be on the secondary coil? If the transformer were 100% efficient, what current would flow through the primary coil when the current in the secondary coil was 0.4 A? **Ans. (200, 0.02A)**

15.5. A power station generates 500 MW of electrical power which is fed to a transmission line. What current would flow in the transmission line, if the input voltage is 250 kV? **Ans. (2×10^3 A)**



Unit 16
BASIC ELECTRONICS

After studying this unit, students will be able to:

- explain the process of thermionic emission emitted from a filament.
- describe the simple construction and use of an electron gun as a source of electron beam.
- describe the effect of electric field on an electron beam.
- describe the effect of magnetic field on an electron beam.
- describe the basic principle of CRO and make a list of its uses.
- differentiate between analogue and digital electronics.
- state the basic operations of digital electronics.
- identify and draw the symbols for the logic gates (NOT, OR, AND, NOR and NAND).
- state the action of the logic gates in truth table form.
- describe the simple uses of logic gates.

Science, Technology and Society Connections

The students will be able to:

- identify by quoting examples that the modern world is the world of digital electronics.
- identify that the computers are the forefront of electronic technology.
- realize that electronics is shifting from low-tech electrical appliances to high-tech electronic appliances.

Electronics is that branch of applied physics which deals with the control of motion of electrons using different devices. Electronic devices being more effective and reliable have revolutionized the fields of telecommunication and information technology. This chapter aims at providing basic concepts of electronics

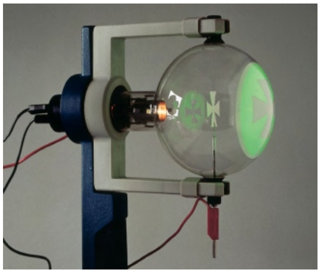
16.1 THERMIONIC EMISSION

In the 1850's, physicists started to examine the passage of electricity through a vacuum by putting two electrodes in a sealed vacuum tube. Some kind of rays were emitted from the cathode or the negative electrode. These rays were called cathode rays. J.J. Thomson in 1897 observed the deflection of cathode rays by both electric and magnetic fields. From these deflection experiments, he concluded that cathode rays must carry a negative charge. These negatively charged particles were given the name electrons.

The process of emission of electrons from the hot metal surfaces is called thermionic emission. Metals contain a large number of free electrons. At room temperature electrons cannot escape the metal surface due to attractive forces of the atomic nucleus. If the metal is heated to a high temperature, some of the free electrons may gain sufficient energy to escape the metal surface.

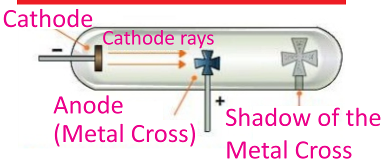
Thermionic emission can also be produced by electrically heating a fine tungsten filament. Typical values of the voltage and current used are 6 V and 0.3 A respectively. Now we examine some important experiments performed for discovering the properties of the electrons.

For your information



In a cathode-rays tube, a greenish glow is formed on the inner surface of the glass opposite the cathode, which itself is glowing orange here. The shadow cast by the cross at the centre of the tube gives evidence that rays of some kind are passing through the tube.

Phyics Insight



When an opaque object like a metal cross is placed in the path of cathode rays in a cathode-ray tube, a shadow of the metal cross is formed at the end opposite to the cathode. This is an evidence that rays of some kind are passing straight through the tube.

16.2 INVESTIGATING THE PROPERTIES OF ELECTRONS

An electron gun (Fig. 16.1) is used to investigate the properties of electron beam. The electrons are produced by thermionic emission from a tungsten filament heated by 6 V supply. A high positive potential (several thousands) is applied to a cylindrical anode (+). The electrons are accelerated to a high speed and pass through the hole of the anode in the form of a fine beam of electrons. The whole set up is fitted in an evacuated glass bulb.

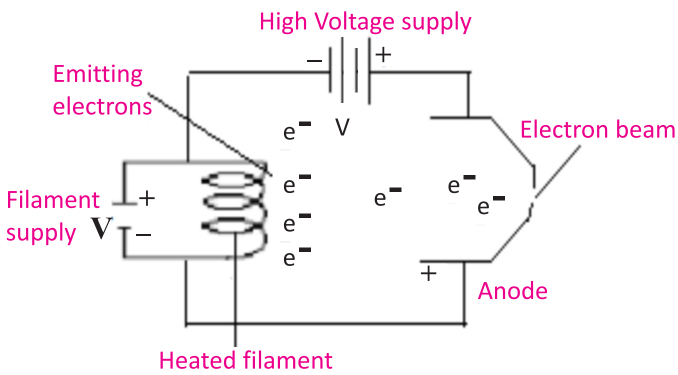


Fig. 16.1: Electron gun

Deflection of electrons by electric field

We can set up electric field by applying a potential difference across two parallel metal plates placed horizontally separated by some distance. When an electron beam passes between the two plates, it can be seen that the electrons are deflected towards the positive plate (Fig.16.2). The reason for this is that electrons are attracted by the positive charges and are repelled by the negative charges due to force $F=qE$, where 'q' is the electron charge and E is the electric field due to plates. The degree of deflection of electrons from their original direction is proportional to the strength of the electric field applied.

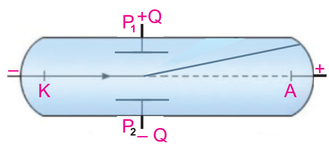


Fig 16.2: Deflection of cathode rays by an electric field

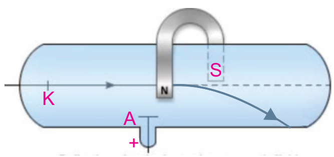
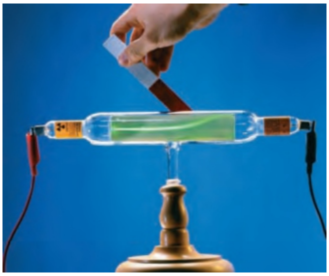


Fig.16.3: Deflection of cathode rays by a magnetic field

Deflection of electrons by magnetic field

Now we apply magnetic field at right angle to the beam of electrons by using a horseshoe magnet (Fig. 16.3). We will

notice that the spot of the electrons beam on the screen is getting deflected from its original direction. Now change the direction of the horseshoe magnet. We will see that spot on the fluorescent screen is getting deflected in the opposite direction.



A cathode ray will deflect as shown when it is under the influence of an external magnetic field.

16.3 CATHODE-RAY OSCILLOSCOPE (C.R.O)

The cathode-ray oscilloscope is an instrument which is used to display the magnitudes of changing electric currents or potentials (Fig. 16.4). The information is displayed on the screen of a "cathode-ray tube". This screen appears as a circular or rectangular window usually with a centimetre graph superimposed on it. For example, the picture tube in our TV set and the display terminal of most computers are cathode-ray tubes.

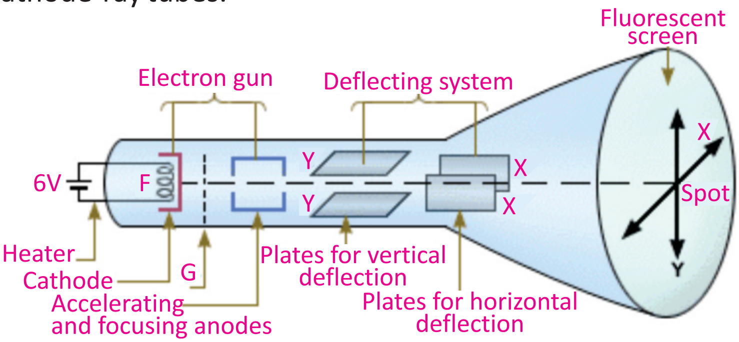


Fig. 16.4: Cathode-Ray Oscilloscope

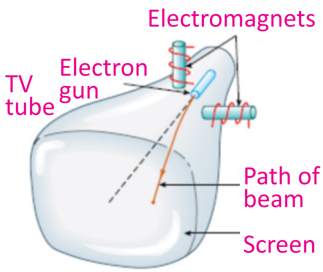
Point to ponder!

When a magnet is brought near to the screen of a television tube, picture on the screen is distorted. Do you know why?

The cathode-ray oscilloscope (C.R.O) consists of the following components:

- The electron gun with control grid
- The deflecting plates
- A fluorescent screen

Do you know?



Electromagnets are used to deflect electrons to desired positions on the screen of a television tube.

The Electron Gun

The electron gun consists of an electron source which is an electrically heated cathode that ejects electrons. Electron gun also has an electrode called grid G for controlling the flow of electrons in the beam. The grid is connected to a negative potential. The more negative this potential, the more

electrons will be repelled from the grid and hence fewer electrons will reach the anode and the screen. The number of electrons reaching the screen determines the brightness of the screen. Hence, the negative potential of the grid can be used as a brightness control. The anode is connected to positive potential and hence is used to accelerate the electrons. The electrons are focused into a fine beam as they pass through the anode.

The Deflecting Plates

After leaving the electron gun, the electron beam passes between a pair of horizontal plates. A potential difference applied between these plates deflects the beam in a vertical plane. This pair of plates provides the Y-axis or vertical movement of the spot on the screen. A pair of vertical plates provides the X-axis or horizontal movement of the spot on the screen.

The Fluorescent Screen

The screen of a cathode-ray tube consists of a thin layer of phosphor, which is a material that gives light as a result of bombardment by fast moving electrons.

The CRO is used in many fields of science; displaying waveforms, measuring voltages, range-finding (as in radar), echo-sounding (to find the depth of seabeds). The CRO is also used to display heartbeats.

16.4 ANALOGUE AND DIGITAL ELECTRONICS

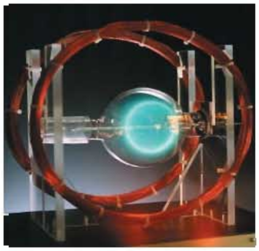
The quantities whose values vary continuously or remain constant are known as analogue quantities. For example, the temperature of air varies in a continuous fashion during 24 hours of a day. If we plot a graph between time and temperature recorded at different times, we get a graph (Fig.16.5-a). This graph shows that temperature varies continuously with time. Therefore, we say that temperature is an analogue quantity. Similarly, time, pressure, distance, etc. are analogue quantities.

Do you know?

Cathode Rays

The beam of electrons was called a cathode ray, because the electron had not yet been discovered. The old terminology survives in electronic engineering where a cathode-ray tube is any tube constructed along Thomson's lines whether in a computer monitor, a television, or an oscilloscope.

Do you know?



The glow in the tube is due to circular motion of electron in the magnetic field. The glow comes from the light emitted from the excitations of the gas atoms in the tube.

The branch of electronics consisting of circuits which process analogue quantities is called analogue electronics. For instance, the public address system is an analogue system in which the microphone converts sound into a continuously varying electric potential. This potential is an analogue signal which is fed into an amplifier. Amplifier is an analogue circuit which amplifies the signal without changing its shape to such an extent that it can operate a loudspeaker. In this way, loud sound is produced by the speaker. Radios, televisions and telephones are a few common devices that process analogue signals.

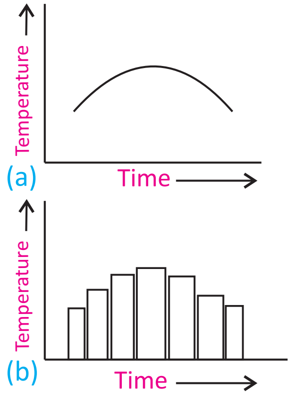
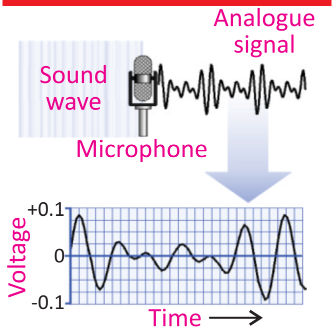


Fig.16.5: An analogue signal

The quantities whose values vary in non-continuous manner are called digital quantities. Digital version of analogue signal is shown in Fig.16.5 (b). Digital quantities are expressed in the form of digits or numbers. The branch of electronics which deals with digital quantities is called digital electronics. Digital electronics uses only two digits '0' (zero) and '1' (one) and the whole data is provided in binary form due to which processing of data becomes easy.

Do you know?



Microphone creates an analogue signal, shown by the voltage versus time graph.

Fig 16.6 shows an analogue and digital signal. A continuously varying signal is called an analogue signal. For example, an alternating voltage varying between the maximum value of +5V and the minimum value of -5V is an analogue signal (Fig. 16.6-a). A signal that can have only two discrete values is called a digital signal. For example, a voltage with square waveform is a digital signal (Fig.16.6-b). This signal has only two values i.e., +5 V and 0 V. The High voltage is +5 V and the low voltage is 0 V. It can be seen that digital signal provides the data by a maximum and a minimum voltage level. The changes occurring in the digital signal are not continuous. For quite a long period, the use of digital electronics was limited to computers only, but now-a-days its application is very wide spread. Modern telephone system, radar system, naval and other systems of military importance, devices to control the operation of industrial machines, medical equipments and many

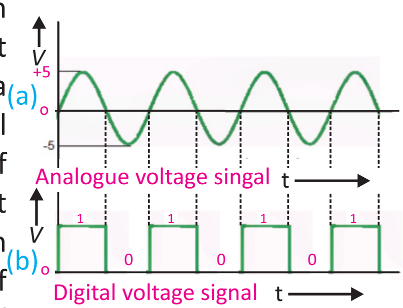


Fig.16.6

household appliances are using digital technology.

In our daily life, the quantities that we perceive by our senses are usually analogue quantities which cannot be processed by digital circuits. To overcome this problem, a special circuit has been designed which converts in binary form the analogue signal into a digital one in the form of digits in binary form. This circuit is known as analogue to digital converter (ADC). This binary output is then processed by a computer which also gives output in digital form. The output of the computer is again converted into an analogue form by a circuit known as digital to analogue converter (DAC). As the output of DAC is an analogue signal, it can be readily sensed by us. Thus, electronic systems used at present consist of both analogue and digital type circuits.

For your information

Digital technology has entered every part of our lives. Digital TV gives excellent view and allows us to be interactive. Digital cameras are fast replacing traditional film equipment. We can download an image into a PC and crop, enhance, airbrush and edit the picture. Smart ID cards are being developed. A single card can be a passport, national insurance card and driving license all in one. The card could also hold biometric data like an eye retina scan and voice scan for unique identification and security. All of this data would be held digitally in the tiny chip.

16.5 BASIC OPERATIONS OF DIGITAL ELECTRONICS – LOGIC GATES

A switch has only two possible states. It could be either open or closed. Similarly, a given statement would be either true or false. Such things which can have only two possible states are known as binary variables. The states of binary variables are usually represented by the digits '0' and '1'.

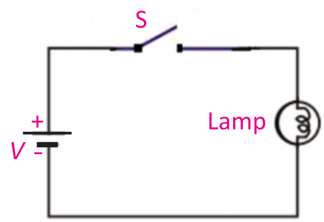


Fig. 16.7

Suppose we form a circuit by connecting a lamp to a battery using a switch S (Fig. 16.7). We call state of switch as input and state of current or lamp as output. When the switch is open no current passes through the circuit and lamp is OFF. In other words, when input is zero output is also zero. When the switch is closed current passes through the circuit and lamp is ON. Thus, the output current is also a binary variable. In case, the current is passing, we can say the value of the output is '1' and it is '0' when no current is passing. The possible combinations of input and output states of this circuit are shown in Table 16.1.

Table 16.1

S	Lamp
Open	OFF
Closed	ON

These states are also called logic states or logic variables. Now the question arises that if the values of input variables of

a circuit or a system are known, then how can we determine the value of output? To answer this question, George Boole invented a special algebra called Boolean algebra also known as algebra of logics. It is a branch of mathematics which deals with the relationships of logic variables. Instead of variables that represent numerical quantities as in conventional algebra, Boolean algebra handles variables that represent two types of logic propositions; 'true' and 'false'.

Boolean algebra has become the main cornerstone of digital electronics. It operates with two logic states, '1' and '0', represented by two distinct voltage levels. Boolean algebra's simple interpretation of logical operators AND, OR, and NOT has allowed the systematic development of complex digital systems. These include simple logic gates that perform simple mathematical as well as intricate logical operations. Logic operations may be thought of as a combination of switches.

Since a logic gate is a switching circuit (i.e., a digital circuit), its outputs can have only one of the two possible states. either a high voltage ‘1’ or a low voltage ‘0’ – it is either ON or OFF. Whether the output voltage of logic gate is high ‘1’ or low ‘0’ will depend upon the condition at its input.

Now we discuss some basic logic operations and logic gates that implement these logic operations.

16.6 AND OPERATION

In order to understand the logic AND operation see the Fig 16.8 in which a lamp is connected to a battery using two switches S_1 and S_2 connected in series considered as two inputs. There are four possible states of these two switches which are given below:

(i) When S_1 and S_2 are both open, the lamp is OFF.
(ii) When S_1 is open but S_2 closed, the lamp is OFF.
(iii) When S_1 is closed but S_2 open, the lamp is OFF.
(iv) When both S_1 AND S_2 are closed, the lamp is ON.

Do you know?

TV and telephone signals once travelled as analogue signals. Electrical signals in copper wires would interfere with each other and give poor quality sound and vision. Today, everything is going digital. The big advantage of digital is quality. There is no interference or loss of strength in digital signal travelling in an optical fibre.

Introduction to Boolean Algebra

The algebra used to describe logic operations by symbols is called **Boolean Algebra.** Like ordinary algebra, English alphabets (A, B, C, etc.) are used to represent the Boolean variables. However, Boolean variable can have only two values; 0 and 1.

Digital circuits perform the binary arithmetic operations with binary digits ‘1’ and ‘0’. These operations are called logic function or logical operations.

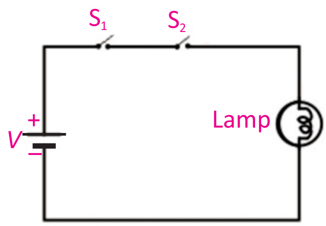


Fig. 16.8

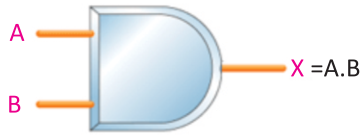
The four possible combinations of switches S_1 and S_2 are shown in the Table 16.2. It is clear that when either of the switches (S_1 or S_2) or both are open, the lamp is OFF. When both switches are closed, the lamp is ON.

Symbol for AND operation is dot (.). Its Boolean expression is: X = A . B and is read as **" X equals A AND B"**.

Set of inputs and outputs in binary form is called truth table. In binary language, when either of the inputs or both the inputs are low (0), the output is low (0). When both the inputs are high (1), the output is high (1). The truth table of AND operation is shown in Table 16.3, where X represents the output. Therefore, AND operation may be represented by switches connected in series, with each switch representing an input. When two switches are closed i.e., the inputs of the AND operation are at logic '1', the output of the AND operation will be at logic '1'. But when two switches are open i.e., the inputs of AND operation are at logic '0', the output of AND operation will be at logic '0'. For any other state of two switches (i.e., the input of AND operation), the output will be '0'.

Table 16.2

S_1	S_2	Lamp
Open	Open	OFF
Open	Closed	OFF
Closed	Open	OFF
Closed	Closed	ON



AND gate

Fig. 16.9

The circuit which implements the AND operation is known as AND gate. Its symbol is shown in Fig. 16.9. AND gate has two or more inputs and only one output. The value of output of AND gate is always in accordance with the truth table of AND operation. It means output of AND gate will be '1' only when all of its inputs are at logic '1', and for all other situations output of AND gate will be '0'.

Table 16.3

A	B	X = A.B
0	0	0
0	1	0
1	0	0
1	1	1

16.7 OR OPERATION

In order to understand the logic OR operation see the circuit shown in Fig.16.10. A lamp is connected to a battery using two switches S_1 and S_2 connected in parallel considered as

two inputs. There are four possible states of these two switches which are given below:

(i) When S_1 and S_2 are open, the lamp is OFF.

(ii) When S_1 is open and S_2 closed, the lamp is ON.

(iii) When S_1 is closed and S_2 open, the lamp is ON

(iv) When both S_1 and S_2 are closed, the lamp is ON.

As evident from the circuit in Fig. 16.10, the lamp will glow if at least one of the switches is closed. In the language of Boolean algebra, we say the lamp will glow at least one of the values of S_1 and S_2 is at logic '1'.

Table 16.4 describes all possible states of the switches for the 'OR' operation.

OR operation is represented by the symbol of plus (+). Boolean expression for OR operation is : X = A + B and is read as " X equals A OR B". Truth table of OR operation is shown in Table 16.5. An OR operation may be represented by switches connected in parallel, since only one of these parallel switches need to turn on in order to flow current in the circuit.

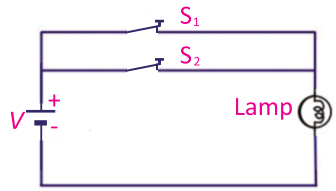
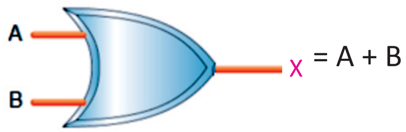


Fig. 16.10



OR gate

Fig.16.11

Table 16.4

S_1	S_2	Lamp
Open	Open	OFF
Open	Closed	ON
Closed	Open	ON
Closed	Closed	ON

The electronic circuit which implements the OR operation is known as OR gate. Symbolically, OR gate is shown in Fig. 16.11. It has two or more inputs and has only one output. The values of output of OR gate are always in accordance with the truth table of OR operation. It means, the value of output of OR gate will be '1' when anyone of its inputs is at '1'. The output will be '0', when all inputs are at '0'.

Table 16.5

A	B	X = A+B
0	0	0
0	1	1
1	0	1
1	1	1

16.8 NOT OPERATION

In order to understand NOT operation, see the circuit shown in Fig. 16.12. A lamp is connected to a battery with a switch S, in parallel When the switch is open, current will pass through the lamp and it will glow. When switch is closed, no current

will pass through the lamp due to large resistance of its filament and it will not glow. States of the switch and the lamp are shown in Table 16.6.

NOT operation is represented by a line or bar over the symbol i.e., $X = \overline{A}$ and is read as "X equals A NOT".

It means NOT operation changes the state of a Boolean variable. For example, if the value of a Boolean variable is 1, then after NOT operation its value would change to '0'. Similarly, if its value before NOT operation is 0, then after NOT operation it would change to '1'. Thus NOT operation inverts the state of Boolean variable. Truth table of NOT operation is given in Table 16.7.

The electronic circuit which implements NOT operation is known as NOT gate. Symbol of NOT gate is shown in Fig. 16.13. It has only one input and one output terminal. NOT gate works in such a way that if its input is 0, its output would be '1'. Similarly, if its input is '1', then output would be '0'.

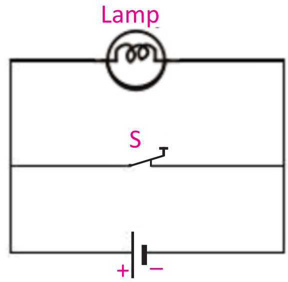


Fig. 16.12

Table 16.6

S	Lamp
Open	ON
Closed	OFF

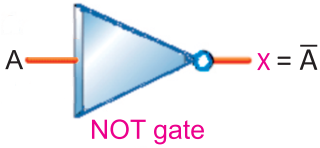


Fig. 16.13

Table 16.7

A	$X = \overline{A}$
0	1
1	0

NOT gate performs the basic logical function called inversion or complementation. NOT gate is also called inverter. The purpose of this gate is to convert one logic level into the opposite logic level. When a HIGH level is applied to an inverter, a LOW level appears on its output and vice versa.

16.9 NAND GATE

NAND operation is simply an AND operation followed by a NOT operation. For example, NAND gate is obtained by coupling a NOT gate with the output terminal of the AND gate (Fig. 16.14-a).

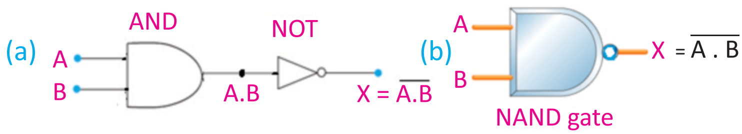


Fig.16.14

The NOT gate inverts the output of the AND gate. The output of the NAND equals $\overline{A.B}$ and is written as $X = \overline{A.B}$. It is read as X equals A AND B NOT. Symbol of NAND gate is shown in Fig. 16.14-b. As shown in the figure, the NOT gate has been replaced with a small circle. In the symbol of NAND gate, this small circle attached at the output of NAND gate given NOT operation. Truth table of NAND gate is given in Table 16.8.

For your information

A	Output
0	1
1	0

A	Output
0	1
1	0

Formation of NOT gate from NAND and NOR gates with the resultant truth tables.

Table 16.8

A	B	$X = \overline{A.B}$
0	0	1
0	1	1
1	0	1
1	1	0

16.10 NOR GATE

The NOR operation is simply an OR operation followed by a NOT operation. The NOR gate is obtained by coupling the output of the OR gate with the NOT gate (Fig.16.15-a). Thus, for the same combination of inputs, the output of a NOR gate will be opposite to that of an OR gate. Its Boolean expression is $X = \overline{A + B}$. It is read as X equals A OR B NOT. Symbol of NOR gate is shown in Fig. 16.15(b). Table 16.9 is the truth table of NOR gate.

Table 16.9

A	B	$X = \overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

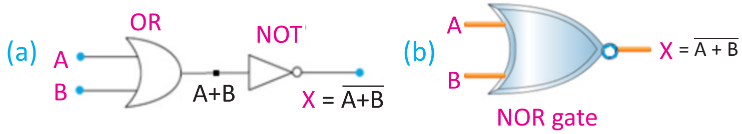


Fig. 16.15

16.11 USES OF LOGIC GATES

We can use logic gates in electronic circuits to do useful tasks. These circuits usually use light depending resistors (LDRs) to keep inputs LOW. An LDR can act as a switch that is closed when illuminated by light and open in the dark.

For your information

$$X = \overline{\overline{A}} = A$$

$$X = \overline{\overline{A + B}} = A + B$$

$$X = \overline{\overline{A.B}} = A.B$$

Here double line indicates double NOT operation.

House Safety Alarm

We can use single NAND gate to make burglar alarm. This can be done by using NAND gate, an LDR, a push-button switch S and an alarm (Fig. 16.16). Connect LDR between NAND gate

input B and the positive terminal of the battery. The LDR will cause a HIGH level input ‘1’ at B when in light because of its Low resistance. The LDR will cause a Low level input ‘0’ at B when light is interrupted and causes high resistance in LDR. A LOW level signal is also caused at A when burglar steps on switch S. So this burglar alarm sounds when either burglar interrupts light falling on LDR or steps on switch S.

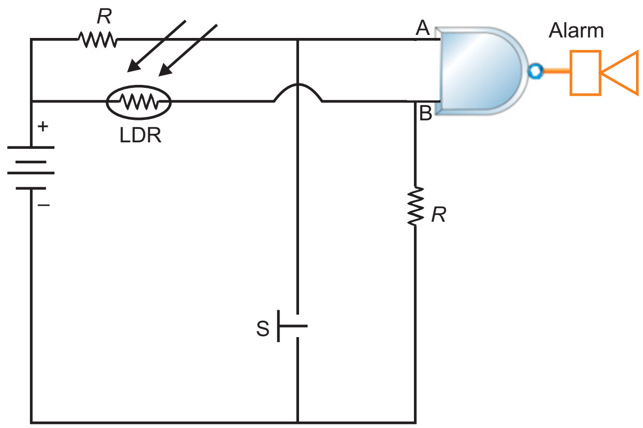


Fig. 16.16: Burglar alarm schematic circuit

Quick Quiz

Assume you have an OR gate with two inputs, A and B. Determine the output, C, for the following cases:

(a) A = 1, B = 0

(b) A = 0, B = 1

If either input is one, what is the output?

For your information

Most of today's technologies fall under the classification of digital electronics.

Digital electronics devices store and process ***bits*** electronically. A ***bit*** represents data using 1's and 0's. Eight bits is a ***byte*** – the standard grouping in digital electronics.

Digitization is the process of transforming information into 1's and 0's.

SUMMARY

- Electronics is that branch of applied physics which deals with the control of motion of electrons in different devices for various useful purposes.
- The process of emission of electrons from the surface of hot metal is called thermionic emission.
- Cathode rays are electrons which are emitted from the hot surface of cathode and travel towards anode due to potential difference.
- Beam of electrons emitted from cathode surface can be deflected by electric and magnetic fields.
- The cathode-ray oscilloscope is an instrument which can be used to display the magnitudes of rapidly changing electric current or potential. It consists of the following three parts: the electron gun, the deflecting plate and a fluorescent screen.
- Those quantities which change continuously with time are known as analogue quantities. And the quantities which change in discrete steps are called digital quantities.
- Electronic devices have become integral part of our daily lives. Television, computers, cell phone, audio and video cassette recorders and players, radio, hi-fi sound system have made our lives more comfortable and pleasant.
- The branch of electronics which processes the data being provided in the form of analogue quantities is called analogue electronics.
- The branch of electronics which processes the data being provided in the form of digits is known as digital electronics.
- Logic gates are the circuits which implement the various logic operations. These are digital circuits which have one or more inputs but only one output.
- There are three basics logic gates: AND gate, OR gate and NOT gate. While NAND gate and NOR gate are combinations of these basic gates.
- The AND gate is a logic gate that gives an output of '1' only when all of its inputs are '1'. The OR gate is a logic gate that gives an output of '0' only when all of its inputs are '0'. The NOT gate is a logic gate that gives an output that is opposite to the state of its input.
- The truth tables are tables which give the values of the inputs and outputs of the basic types of logic gates or combination of such gates.

MULTIPLE CHOICE QUESTIONS

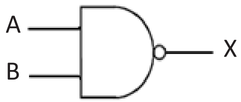
Choose the correct answer from the following choices:

i. The process by which electrons are emitted by a hot metal surface is known as

(a) boiling	(b) evaporation
(c) conduction	(d) thermionic emission

ii. The particles emitted from a hot cathode surface are
(a) positive ions (b) negative ions
(c) protons (d) electrons

iii. The logical operation performed by this gate is



(a) AND (b) NOR
(c) NAND (d) OR

iv. AND gate can be formed by using two
(a) NOT gates (b) OR gates
(c) NOR gates (d) NAND gates

v. The output of a two-input NOR gate is 1 when:
(a) A is ‘1’ and B is ‘0’ (b) A is ‘0’ and B is ‘1’
(c) both A and B are ‘0’ (d) both A and B are ‘1’

vi. If X = A.B, then *X* is ‘1’ when:
(a) A and B are ‘1’ (b) A or B is ‘0’
(c) A is ‘0’ and B is ‘1’ (d) A is ‘1’ and B is ‘0’

vii. The output of a NAND gate is ‘0’ when
(a) both of its inputs are ‘0’ (b) both of its inputs are ‘1’
(c) any of its inputs is ‘0’ (d) any of its inputs is ‘1’

REVIEW QUESTIONS

16.1. Describe, using one simple diagram in each case, what happens when a narrow beam of electrons is passed through (a) a uniform electric field (b) a uniform magnetic field. What do these results indicate about the charge on electron?

16.2. Explain the working of different parts of oscilloscope.

16.3. Name some uses of oscilloscope.

16.4. Considering an oscilloscope explain:
(i) How the filament is heated?
(ii) Why the filament is heated?
(iii) Why the anode potential is kept positive with respect to the cathode potential?
(iv) Why a large potential is applied between anode and cathode?
(v) Why the tube is evacuated?

16.5. What is electron gun? Describe the process of thermionic emission.

16.6. What do you understand by digital and analogue quantities?

16.7. Differentiate between analogue electronics and digital electronics. Write down names of five analogue and five digital devices that are commonly used in

everyday life.

16.8. State and explain for each case whether the information given by the following devices is in analogue or a digital form.

a. a moving-coil voltmeter measuring the e.m.f of a cell.
b. a microphone generating an electric current.
c. a central heating thermostat controlling the water pump.
d. automatic traffic lights controlling the flow of traffic.

16.9. Write down some benefits of using digital electronics over analogue electronics.

16.10. What are the three universal Logic Gates? Give their symbols and truth tables.

CONCEPTUAL QUESTIONS

16.1. Name two factors which can enhance thermionic emission.

16.2. Give three reasons to support the evidence that cathode rays are negatively charged electrons.

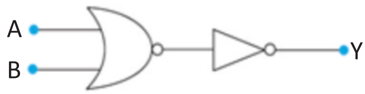
16.3. When electrons pass through two parallel plates having opposite charges, they are deflected towards the positively charged plate. What important characteristic of the electron can be inferred from this?

16.4. When a moving electron enters the magnetic field, it is deflected from its straight path. Name two factors which can enhance electron deflection.

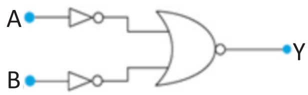
16.5. How can you compare the logic operation X=A.B with usual operation of multiplication?

16.6. NAND gate is the reciprocal of AND gate. Discuss

16.7. Show that the circuit given below acts as OR gate.



16.8. Show that the circuit given below acts as AND gate.



Unit 17

INFORMATION AND COMMUNICATION TECHNOLOGY

After studying this unit, students will be able to:

- describe the components of information technology.
- explain briefly the transmission of
  1. electric signals through wires
  2. radiowaves through air
  3. light signals through optical fibres
- describe function and use of fax machine, cell phone, photo phone and computer.
- make a list of the use of E-mail and internet.
- describe the use of information storage devices such as audio cassettes, video cassettes, hard discs, floppy, compact discs and flash drive.
- identify the functions of word processing, data managing, monitoring and controlling.

Science, Technology and Society Connections

The students will be able to:

- compare the advantages of high-tech. communication devices with the traditional system through library or internet search.
- access the risks and benefits to society and the environment of introducing ICT (e.g. effects on personal privacy, criminal activities, health and transfer of information).
- make a list of the use of computer technology in various fields of daily life.

We are living in the age of information and communication technology. It is not long ago when the telephone was the only device of communication within the country or abroad. Now-a-days, in addition to telephone, mobile phone, fax machine, computer and internet are the main sources of contact. These sources have shortened the distances and have brought in contact the whole world. In this chapter, we will study some basic phenomena and devices which are used in modern day information and communication technology. But before going ahead we should know what this information and telecommunication technology is.

17.1 INFORMATION AND COMMUNICATION TECHNOLOGY

In computer terminology, processed data is called information. Computer processes the data and converts it into useful information. This information is transmitted to distant places in the form of sound, picture and computerized data.

Information and Communication Technology (ICT) is basically an electronic based system of information transmission, reception, processing and retrieval. ICT is a blend of two fields: information technology and telecommunication. The two terms are defined as follows:

1. The scientific method used to store information, to arrange it for proper use and to communicate it to others is called information technology.
2. The method that is used to communicate information to far off places instantly is called telecommunication.

Information and Communication Technology (ICT) is defined as the scientific methods and means to store, process and transmit vast amounts of information in seconds with the help of electronic equipments.

For your information

All modern telecommunications use some form of electromagnetic radiation. Radiowaves carry information to local radio and TV. Microwaves are used for mobile phones, radar and transmission to satellites in space.

17.2 COMPONENTS OF COMPUTER BASED INFORMATION SYSTEM (CBIS)

There are five parts that must come together in order to produce

a Computer-Based Information System (CBIS) as shown in Fig.17.1. These are called the components of information technology. Now we discuss these components briefly.

1. Hardware: The term hardware refers to machinery. This includes the central processing unit (CPU), and all of its support equipment. Among the support equipments are input and output devices, storage devices and communication devices.

2. Software: The term software refers to computer programs and the manuals that support them. Computer programs are machine-readable instructions that direct the circuitry within the hardware parts of the CBIS to produce useful information from data. Programs are generally stored on some input / output medium, often a disk or tape.

3. Data: Data are facts and figures that are used by programs to produce useful information. It may be in the form of text, graphic or figure that can be recorded and that have specific meaning. Like programs, data are generally stored in machine-readable form on disk or tape until the computer needs them.

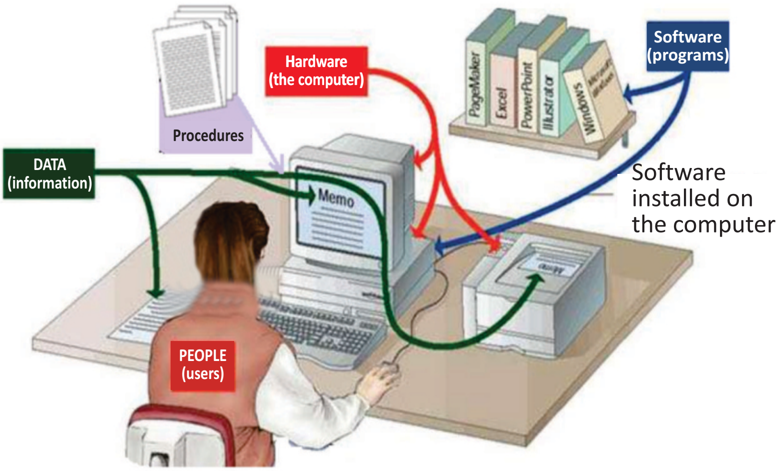


Fig. 17.1: Components of CBIS

4. Procedures: These are set of instructions and rules to design and use information system. These are written in manuals and documents for use. These rules or methods may change from time to time. The Information System must be flexible to incorporate these changes.

5. People: Every CBIS needs people if it is to be useful, who influence the success or failure of information systems. People design and operate the software, they feed input data, build the hardware for the smooth running of any CBIS. People write the procedures and it is ultimately people who determine the success or failure of a CBIS.

17.3 FLOW OF INFORMATION

Flow of information means the transfer of information from one place to another through different electronic and optical equipments. In telephone, information is sent through wires in the form of electrical signals. In radio, television and cell phone information is sent either through space in the form of electromagnet waves, or through optical fibres in the form of light. Radiowaves are continuously refracted by different layers in the Earth's atmosphere. This leads to weaken the signal, making it difficult to be received over long distances. Unlike radiowaves, microwaves are not refracted. They are used for satellite communication.

Fig. 17.2 shows the elements of a communication system. There are three essential parts of any communication system: transmitter, transmission channel, and receiver.

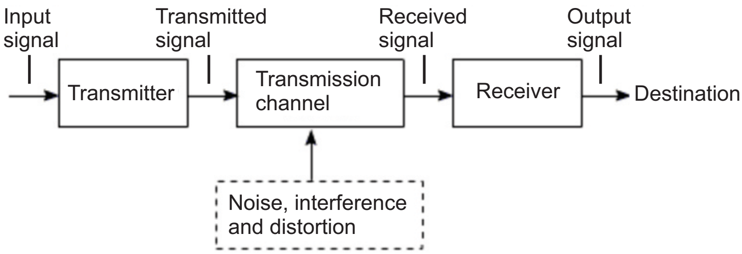
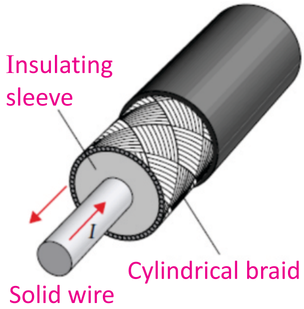


Fig. 17.2

The transmitter processes the input signal. The transmission channel is the medium which sends the signal from source to destination. It may be a pair of wires, a coaxial cable, a radio-wave or optical fibre cable. So, the signal power progressively decreases with increasing distance. The receiver takes the output signal from the transmission channel and delivers it to the transducer after processing it. The receiver may amplify the input signal to compensate for transmission loss.

For your information



Coaxial cable wires are used to transmit electric signals such as cable TV to our homes. To prevent electric and magnetic interference from outside, a covering of conducting material surrounds the coaxial wires.

17.4 TRANSMISSION OF ELECTRICAL SIGNAL THROUGH WIRES

Alexander Graham Bell in 1876 made a simple telephone model to send voice in the form of electrical signal from one place to another. It consists of a metal reed, an electric coil, and a vibrating diaphragm. Modern telephone also uses diaphragms to turn voices into electrical signal that are transmitted over phone lines. Telephone system has two parts: the mouthpiece and the earpiece (Fig.17.3).

The mouthpiece and receiver contain carbon granules and a thin metal diaphragm. When we speak into the mouthpiece, the sound vibrations also vibrate the diaphragm. A slight vibration of the diaphragm compresses the carbon and thus an electrical current can flow through the wire.

This process is reversed at the other end of the line by the receiver. The electrical current flowing through an electromagnet in the receiver produces a varying magnetic field. This magnetic field attracts the thin metal diaphragm in the receiver, causing it to vibrate. This vibration of the diaphragm produces sound waves.

Fig.17.3: Telephone diagram

Interesting information

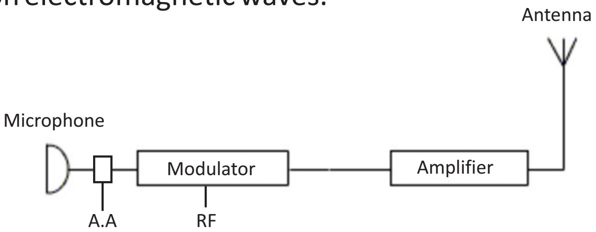
The speed of sound in air is just 1246 km per hour and it cannot go far away from its source. Therefore, it is converted into electromagnetic wave so that they can be sent to far off areas with the speed of light.

17.5 TRANSMISSIONS OF RADIOWAVES THROUGH SPACE

Electrical signals representing information from a microphone, a TV camera, or a computer can be sent from one place to another place using either cables or radiowaves. Information in the form of audio frequency (AF) signals may be transmitted directly by cable. However, in order to send information over a long distance, it has to be superimposed on electromagnetic waves.

Do you know?

Radiowaves are electromagnetic waves and they travel with the speed of light. Marconi has the distinction that he transmitted the first radio signal through the air.



Transmitter

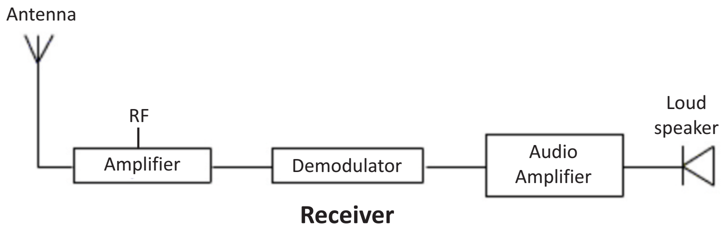


Fig. 17.4: Radio transmission and receiving system

Radio

Sound waves produced at the radio station are changed into electrical signals through microphone. These electric signals are then fed into the transmission antenna which consists of two metal rods. Signals falling on the transmission antenna oscillate the charges which then emit these electrical signals in the form of electromagnetic radiowaves.

At the receiving end, the receiver selects and amplifies the modulated signal. The demodulator then extracts the information signal and delivers it to the receptor. Radio transmission and receiving system is shown in Fig. 17.4.

For your information

Radio tuning circuit consists of coils of fine wire wounded on a rod which is connected to the antenna. The coils are connected to variable capacitors. The tuned circuit selects signals of only particular frequency. It does not amplify the signals from transmitters with slightly lower or higher frequencies. The voltage rises and falls as the frequency of the received signal increases or decreases relative to the constant frequency of the oscillator.

FAX MACHINE

Telefacsimile's or Fax machines (Fig. 17.5) are must for many businesses around the world. A fax machine basically scans a page to convert its text and graphic into electronic signals and transmits it to another fax machine through telephone line. The receiving machine converts the signals and uses a printer (usually built in) to create the copy of the message that was sent.

Fig.17.5: Fax machine

CELL PHONE

Radio technology is applied in mobile phone (Fig. 17.6). It is a type of radio having two way communications. A cell phone carries a radio transmitter and a receiver inside it. It sends and receives the message in the form of radiowaves.

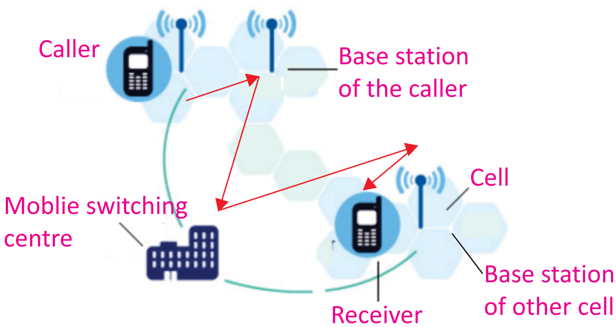


Fig. 17.7: Cell phone network

Fig. 17.6: Cell phone

Cell phone network system consists of cells and **Base Stations (BSs)** and **Mobile Switching Centre (MSC)** **(** Fig. 17.7). A base station is a wireless communication station set up at a particular geographical location. The geographical area covered by a single base station is known as a cell. The group of cells forms a cluster. All BSs within a cluster are connected to a **MSC** using land lines. The MSC stores information about the subscribers located within the cluster and is responsible for directing calls to them. When a caller calls another cell phone, sound waves of the caller are converted into radiowaves signal. This radio signal of particular frequency is sent to the local base station of the caller where the signal is assigned a specific radio frequency. This signal is then sent to the base station of the receiver through MSC. Then the call is transferred to the cell phone of the receiver. Mobile receiver again changes the radiowaves into sound.

PHOTO PHONE

Modern version of photo phone or video phone is shown in Fig 17.8. Contrary to a common telephone, users can see the pictures of each other. By using the photo and phone numbers of our friends or family members on this telephone, we can call them by pressing the pad with their photos. Thus, we can communicate with our relatives or friends on photo phone with the physical appearance of each other.

Fig.17.8: Photo phone

17.6 TRANSMISSION OF LIGHT SIGNALS THROUGH OPTICAL FIBRES

Waves of visible light have a much higher frequency than that of radiowaves. This means, rate of sending information with light beams is larger than that with radiowaves or microwaves. An optical fibre has been used as transmission channel for this purpose. An optical fibre with a coating of lower refractive index is a thin strand of high-quality glass that absorbs very little light. An optical fibre cable is a bundle

Do you know?

A mobile phone sends text messages and takes and transmits images. The new 3G technology will make video phones common place.

of glass fibres with thickness of a human hair.

Light that enters the core at one end of the optical fibre goes straight and hits the inner wall (the cladding) of fibre optics. If the angle of incidence with cladding is less than the critical angle, some of the light will escape the fibre optics and is lost (Fig. 17.9). However, if the angle of incidence is greater than the critical angle, light is totally reflected into the fibre optics. Then the totally reflected beam of light travels in a straight line until it hits the inner wall again, and so on. The advantage of optical fibre is that it can be used for sending very high data rates over long distances. This feature of fibre optics distinguishes it from wires. When electrical signals are transmitted through wires, the signal lost increases with increasing data rate. This decreases the range of the signal.

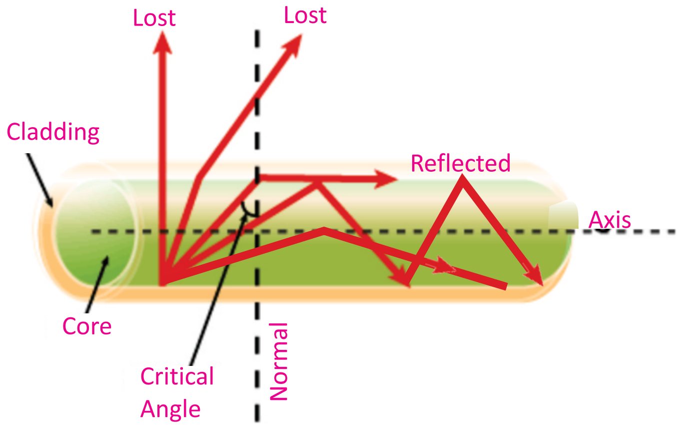


Fig. 17.9: Light entering a glass rod at greater than the critical angle is trapped inside the glass

Each optical fibre in a multi-mode cable is about 10 times thicker than fibre optics used in a single-mode cable. This means light beams can travel through the core by following different paths, hence the name multiple-mode. Multi-mode cables can send information only over relatively short distances and are used to link computer networks together.

COMPUTER

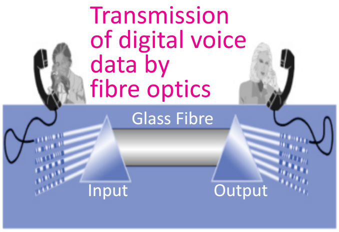
Computer (Fig. 17.10) is an electronic computing machine used for adding, subtracting or multiplying. Computers work through an interaction of hardware and software. Hardware

For your information

Microwave, digital and optical fibre technologies are combined to give us today's telecommunication systems. Microwaves travel in straight lines through the space and give a very strong signal. We can connect to the other side of the world in milliseconds. Communication satellites including **INTELSAT** and **SATCOM** are geostationary satellites that stay over the same position above the Earth surface and receive and transmit digital signals across the world.

Do you know?

Cell phone transmissions are made with microwaves.



Most of the data transmitted across the Internet is also carried by light. A network of fibre optic cables across the country carrying data from one computer to another.

refers to the parts of a computer that you can see and touch. These include CPU, monitor, keyboard, mouse, printer, etc. The most important piece of hardware is the central processing unit (CPU) that contains a tiny rectangular chip called microprocessor. It is the "brain" of computer—the part that translates instructions and performs calculations.

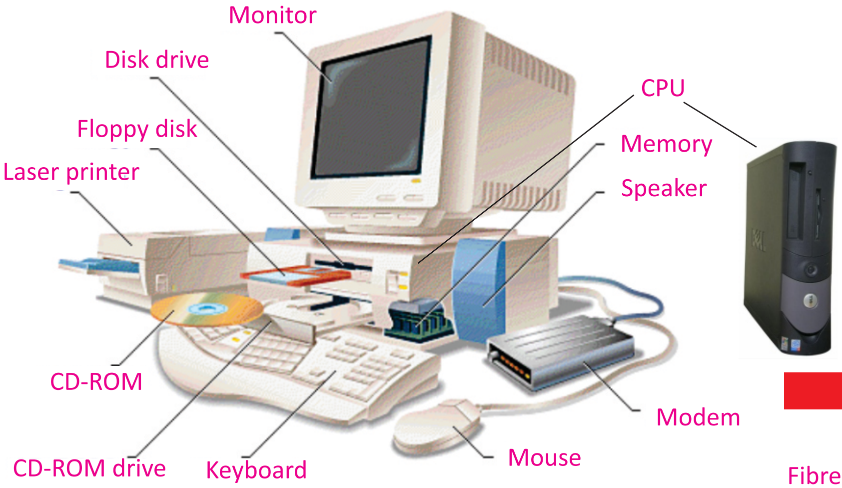
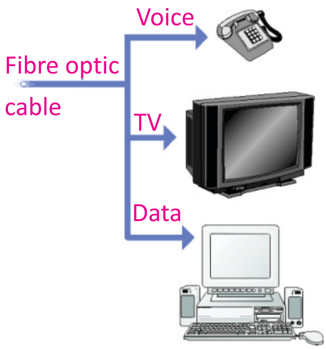


Fig. 17.10: Parts of a computer

Software refers to the instructions, or programs, that tell the hardware what to do. A word processing program that you can use to write letters on your computer is a type of software. The operating system (OS) is software that manages your computer and the devices connected to it. Two well known operating systems are Windows and Linux operating system.

Computer plays an important role in our daily life. In offices, computers are used for preparing letters, documents and reports. In hotels, computers are used for advance booking of rooms, preparing bills and providing enquiry services. In railways, computers are used for rail reservation, printing of tickets and preparation of reservation charts. Doctors use computers for diagnosing illness and treatment of diseases. Architects use them for building designing and city planning. In meteorology department, computers are used for weather forecasting. Now usual desktop computers have been replaced by laptops to a great extent. Laptops (Fig 17.11) are

Do you know?



A single fibreoptic cable can carry more than enough information to support television, telephone, and computer data.

Fig. 17.11: Laptop

more compact and hence are portable.

17.7 INFORMATION STORAGE DEVICES

A storage device is a device designed to store information in computer. Storage devices work on different principles using electronics, magnetism and laser technology.

PRIMARY MEMORY

It is based on electronics and consists of integrated circuits (ICs). It consists of two parts; Read only memory (ROM), which starts the computer and Random access memory (RAM), which is used in computer as temporary memory. RAM vanishes when the computer is switched off.

SECONDARY STORAGE DEVICES

The data storage devices are generally the secondary memory of the computer. It is used to store the data permanently in the computer. When we open a program data is moved from the secondary storage into the primary storage. The secondary storage devices are audio-video cassettes and hard disk etc.

AUDIO AND VIDEO CASSETTES

These devices are based on magnetism. Audio cassettes consist of a tape of magnetic material on which sound is recorded in a particular pattern of a magnetic field(Fig. 17.12). For this purpose, microphone changes sound waves into electric pulses, which are amplified by an amplifier. Magnetic tape is moved across the head of audio cassette recorder which is in fact an electromagnet (Fig 17.13).

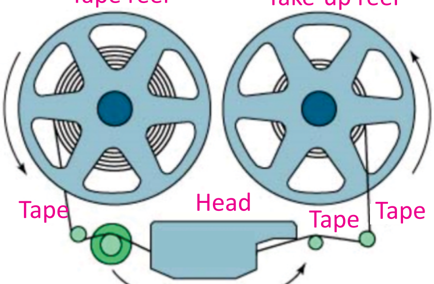


Fig. 17.13: A magnetic tape storage mechanism

For your information

Computers use data in binary from i.e., in the form of 0's and 1's. A bit is a single numeric value, either '1' or '0', that encodes a single unit of digital information. A byte is equal to eight bits. Larger units of digital data are kilobytes (kB), megabyte (MB) and gigabyte (GB). These are defined as below:

1 kB = 1024 bytes
1 MB = 1024 kilobytes
1 GB = 1024 megabytes

Fig. 17.12: Audio cassettes

Interesting information

The most powerful and swift computer which can send an information in one thousand billionth part of a second is called super computer. It contains many processors.

Thus magnetic tape is magnetized in a particular pattern according to rise and fall of current. In this way, sound is stored in a specific magnetic pattern on this tape.
To produce the sound again, the tape is moved past the play back head. Changes in the magnetic field on the tape induce alternating current signals in the coil wound on the head. These signals are amplified and sent to the loudspeakers which reproduce the recorded sound. In video tape/cassettes (Fig.17.14), pictures are recorded alongwith sound.

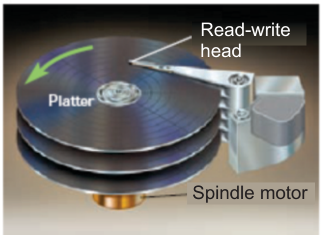
Fig. 17.14: Video cassettes

MAGNETIC DISKS

There are different types of magnetic disks coated with a layer of some magnetic material. The read/write head of disks are similar to the record replay head on a tape recorder. It magnetizes parts of the surface to record information. The difference is that a disk is a digital medium– binary numbers are written and read. A floppy disc (Fig.17.15) is a small magnetically sensitive, flexible plastic wafer housed in a plastic case. It is coated with a magnetic oxide similar to the material used to coat cassettes and video tapes. Most personal computers include at least one disk drive that allows the computer to write it and read from floppy disk
Floppies are inexpensive, convenient, and reliable, but they lack the storage capacity and drive speed for many large jobs. Data stored on floppy disks is also subject to loss as a result of stray magnetic fields. As far as floppy disks are concerned, they are reliable only for short-term storage and cannot be used longer and no attempts should be made to save the data for a longer period. As the magnetic fields weaken the data will also be lost.

Fig. 17.15: Floppy disk

For your information



In computer hard drive, each platter has a magnetizable coating on each side. The spindle motor turns the platters at several thousand resolutions per minute (rpm). There is one read-write head on each surface of each platter.

HARD DISK

Most users rely on hard disks as their primary storage devices. A hard disk is a rigid, magnetically sensitive disk that spins rapidly and continuously inside the computer chassis or in a separate box connected to the computer housing (Fig.17.16). This type of hard disk is never removed by the user. A typical hard disk consists of several

platters, each accessed via a read/write head on a moveable arm.

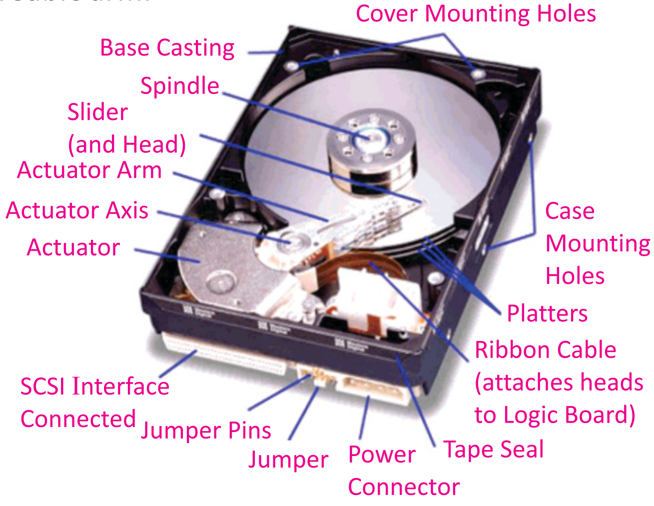


Fig.17.16: Hard disk

COMPACT DISC (CDs)

This is based on laser technology. It is a molded plastic disc on which digital data is stored in the form of microscopic reflecting and non-reflecting spots which are called "pits" and "lands" respectively (Fig.17.17). Pits are the spiral tracks encoded on the top surface of CD and lands are the areas between pits (Fig. 17.18). A fine laser beam scans the surface of the rotating disk to read the data. Pits and lands reflect different amount of the laser light falling on the surface of CD. This pattern of different amount of the light reflected by the pits and the lands is converted into binary data. The presence of pit indicates '1' and absence of pit indicates '0'.

A CD can store over 680 megabyte of computer data. A DVD, the same size as traditional CD, is able to store upto 17gigabytes of data.

Fig. 17.17: Compact disk (CD)

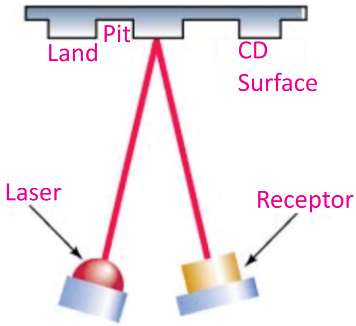


Fig. 17.18

FLASH DRIVE

It is also an electronic based device and consists of data storage ICs. A flash drive is a small storage device that can be used to transport files from one computer to another (Fig. 17.19). They are slightly larger than a stick of gum, yet many of these devices can carry all your homework for an entire year! We can keep one on a key chain, carry it around our neck, or attach it to our book bag.

Fig. 17.19: Flashdrive

A flash drive is easy to use. Once we have created a paper or

other work, we can simply plug our flash drive into a USB port. We must make a backup of our created paper or project on our flash drive and save it separate from our computer. A flash drive will also come in handy if you are able to print out homework at school. You can write a paper at home, save it to your flash drive, and then plug the drive into a USB port on a school computer.

17.8 APPLICATIONS OF COMPUTER

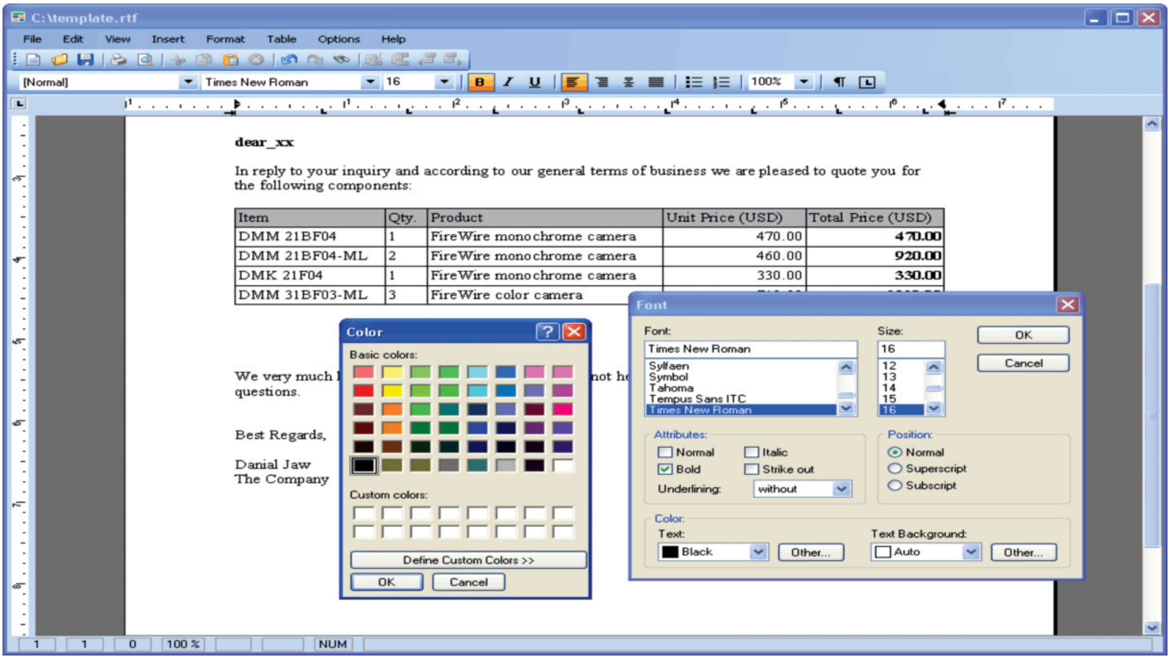
WORD PROCESSING

Word processing is such a use of computer through which we can write a letter, article, book or prepare a report. Word processing is a computer program. Using this program we can develop any document, see it on the screen after typing. We can edit the document, add some new text or delete the previous text or make amendments in it. We can move text from one page to another, even from one document to another. Document can be stored in memory and its print can also be taken. By means of modern word processing, we can write it in different styles and in different colours. We can also use graphics.

Do you know?

If the CD is made of metal or glass, it is called hard disk and if it is made of soft elastic material then it is called floppy.

Some other features of word processing are shown below in the icon of word processing:



DATA MANAGEMENT – MONITORING AND CONTROL

To collect all information regarding a subject for any purpose and to store them in the computer in more than one inter linked files which may help when needed, is called 'data managing'.

The educational institutions, libraries, hospitals and industries store the concerned information by data management. Additions and deletions are made in the data according to the requirement, which help in the improvement of the management of the institutions.

In big departmental stores and super markets, optical scanners are used to read, with the help of a Laser Beam, the barcodes of a product which indicate the number at which this product is recorded in the register (Fig.17.20). In this way, the detail about its price is obtained. The central computer monitors the bills and the related record of the sold goods. It also helps placing the order of goods being sold in a large quantity and to decide about less selling goods.

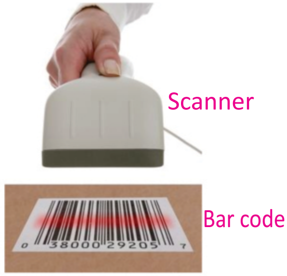


Fig. 17.20: Bar code scanning

Electronic Banking

Now-a-days, home banking is operating on telephones. We can find our bank balance from the bank on phone, can pay all kinds of bills and transfer our funds by pressing a key of our personal identification number. The bank computer, after our identification, sends us all required information. With the help of ATM machines, we can draw money at any time we want.

17.9 INTERNET

When many computer networks of the world were connected together, with the objective of communicating with each other, Internet was formed. In other words, we can say that Internet is a network of networks, which spreads all across the globe. Initially, the size of Internet was small. Soon, people became aware of its utility and advantages and within short span of time, numerous computers and networks got themselves connected to Internet. Its size has increased multi folds within few years. Today Internet comprises of several million computers. There is hardly any country of the world and important city of the country, where Internet is not available.

A conceptual diagram of Internet is illustrated in Fig.17.21. Internet is basically a large computers network, which extends all across the globe. In Internet, millions of computers remain connected together through well-laid communication system.

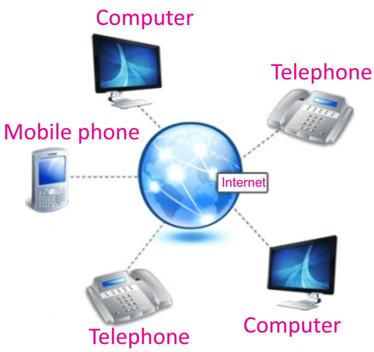


Fig. 17.21: Schematic diagram of Internet

Recall that telephone communication system is well-defined, time proven system. Internet makes use of this system and many other systems to connect all the computers. Thus like a telephone connection, any computer of any city can establish a connection with any other computer of any other city and exchange data or messages with it.

INTERNET SERVICES

The main services used on the internet include:

- Web browsing - this function allows users to view web pages.
- E-mail - Allows people to send and receive text messages.

BROWSERS

A browser is an application which provides a window to the Web. All browsers are designed to display the pages of information located at Web sites around the world. The most popular browsers on the market today include Internet Explorer, The World, Opera, Safari, Mozilla Firefox, Chrome, etc. (Fig. 17.22).

Fig.17.22: Icons of different web browsers

Interesting information

Internet is a global web of more than several million nets in which more than 50 million computers are operating and several millions people participate through the world. The number is increasing day by day. Contact can be made at anytime during the day or night on internet.

Google Chrome Search Engine

Desired Web

We can search anything through search engine like Google Chrome, Internet Explorer, Mozilla Firfox, etc.

Electronic Mail

One of the most widely used application of internet is electronic mail (or e-mail), which provides very fast delivery

of messages to any enabled site on the Internet. Communication through e-mail is more quick and reliable. Through our e-mail, we can communicate with our friends and institution with more ease and pace. Some advantages of e-mail are as follows:

Fast Communication– We can send messages anywhere in the world instantly.

Cost Free Service– If we have an internet access, then we can avail the e-mail service free of cost.

Simple to Use- After initial set up of e-mail account, it is easy to use.

More Efficient– We can send our message to many friends or people only in one action.

Versatile- Pictures or other files can also be sent through e-mail.

Internet has proved to be very beneficial to us. Here is the list of use of internet.

i. Faster Communication **ii. Big Source of Information**
iii. Source of Entertainment **iv. Access to Social Media**
v. Access to Online Services **vi. E-commerce**
vii. E-Learning

17.20 Risks of ICT to Society and the Environment

In this modern age, we are expected to rely upon information technology. But blind faith in modern technology may be dangerous in many cases.

Over use of computer is dangerous for our health. Computer crimes are also very common these days. Computer crime is defined as any crime accomplished through knowledge or use of computer technology.

There is also a word theft. Theft is the most common form of crime. Computers are used to steal money, goods, information and computer resources.

Piracy is another issue of importance which is common on computer. it is the illegal duplication of copyright material like books, papers and software etc.

Hacking is still another illegal activity which is committed on computers. It is an unauthorized access to computer systems of other persons. Computers hackers can damage some organizations by stealing their credit cards and valuable

Yahoo mail icon

For your information

Access of internet to people is increasing day by day. Internet is a useful source of information and knowledge. With broadband you can download information in seconds. E-mail transmits and receives your messages almost instantaneously. . You can talk to your friends and relatives across the continents. A web-cam enables us to hear and see the person you are speaking to.

For your information

E-commerce is the way of doing business on the web. We can order our favourite book or any other items on line. For instance, Amazon.com has been selling books, music and video successfully for years. As time passes on, supermarkets and trading companies will be selling more of their goods on line.

information.

One way to reduce the risk of security breaches is to make sure that only authorized person have access to computer equipment. We may be granted access to computer based on some passwords as described below:

We can use a key, an ID card with photo, an ID number, a lock combination, our voice print or finger print as password to secure our computer.

Point to ponder!

What is the impact of ICT in education?

SUMMARY

- The scientific method used to store information, to arrange it for proper use and to communicate it to others is called information technology.
- The methods and means that are used to communicate information to distant places instantly is called telecommunication.
- Information and Communication Technology (ICT) is defined as the scientific methods and means to store, process and transmit vast amounts of information in seconds with the help of electronic equipment.
- Flow of information means the transfer of the information from one place to another through different electronic and optical equipments.
- In telephone, information can be sent through wires in the form of electrical signals. In radio, television and cell phone information can be sent either through space in the form of electromagnetic waves or it can be sent through optical fibres in the form of light signals.
- There are five parts that must come together in order to produce a Computer-Based Information System (CBIS). These are called the components of information technology. These are: hardware, software, data, procedures and people.
- Information storing devices store the information for later use and benefits. These include audio cassettes, video tapes, compact discs, laser disks, floppy disks, and hard disks.
- Telephone changes sound into electrical signals and sends these signals to the receiver. The receiver changes the electrical signals again to sound by a system fitted in the receiver.
- Mobile phone is a sort of radio with two-way communication. It sends and receives the message in the form of radiowaves.
- Fax machine is the means to send the copy of documents from one place to another through telephone lines.

- Radio is an instrument which transmits the sound waves to us.
- Computer is an electronic computing machine that is used for adding, subtracting and multiplying.
- Hardware refers to the parts of a computer that we can see and touch i.e., key board, monitor, printer, scanner, mouse, etc.
- The most important piece of hardware is the central processing unit (CPU). It is the "brain" of computer—the part that translates instructions and performs arithmetic calculations.
- Software refers to the instructions, or programs, that are installed in the hardware to perform different tasks. Window and Linux Operating Systems (OS) are examples of softwares.
- Word processing is such a use of computer through which we can write a letter, prepare reports and books. By means of this, we can develop any document and see it on the screen after typing.
- To collect information for a special purpose and to store it in a computer in a file form, which may help at times when needed, is called data managing.
- Internet is a network of large number of computers which is major source of information and world communication.

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the following choices:

i. In computer terminology information means
   (a) any data (b) raw data
   (c) processed data (d) large data

ii. Which is the most suitable means of reliable continuous communication between an orbiting satellite and Earth?
   (a) microwaves (b) radiowaves
   (c) sound waves (d) any light wave

iii. The basic operations performed by a computer are
   (a) arithmetic operations (b) non-arithmetic operations
   (c) logical operations (d) both (a) and (c)

iv. The brain of any computer system is
   (a) monitor (b) memory
   (c) CPU (d) control unit

v. Which of the following is not processing?
   (a) arranging (b) manipulating
   (c) calculating (d) gathering

vi. From which of the following we can get information almost about everything.

(a)	book	(b)	teacher
(c)	computer	(d)	internet

vii. What does the term e-mail stand for?

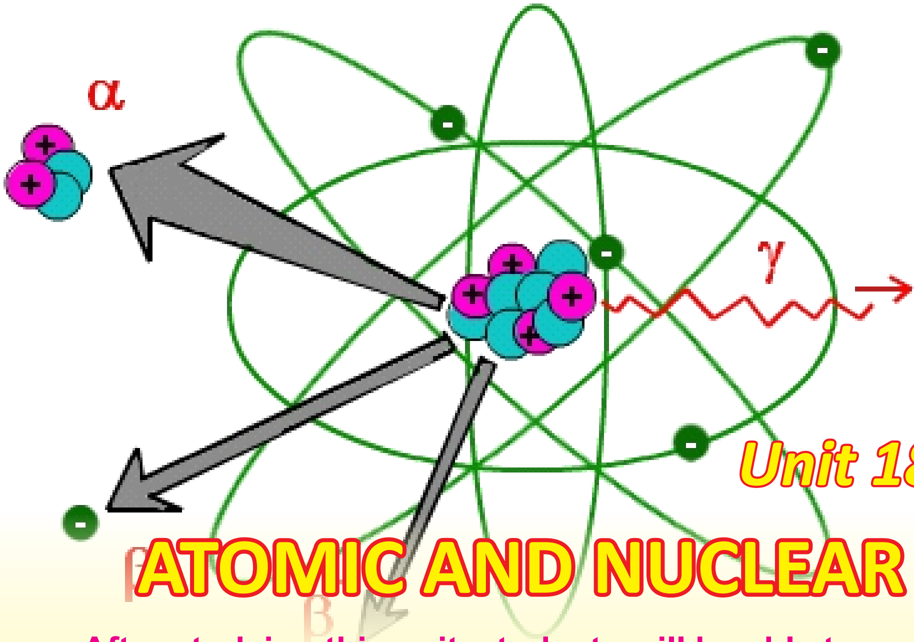
(a)	emergency mail	(b)	electronic mail
(c)	extra mail	(d)	external mail

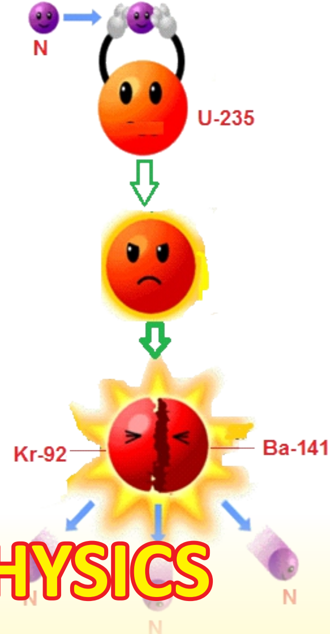
REVIEW QUESTIONS

17.1. What is difference between data and information?
17.2. What do you understand by Information and Communication Technology (ICT)?
17.3. What are the components of information technology? Clearly indicate the function of each component.
17.4. Differentiate between the primary memory and the secondary memory.
17.5. Name different information storage devices and describe their uses.
17.6. Explain briefly the transmission of radiowaves through space.
17.7. How light signals are sent through optical fibre?
17.8. What is computer? What is the role of computer in everyday life?
17.9. What is the difference between hardware and software? Name different softwares.
17.10. What do you understand by the term word processing and data managing?
17.11. What is Internet? Internet is a useful source of knowledge and information. Discuss.
17.12. Discuss the role of information technology in school education.

CONCEPTUAL QUESTIONS

17.1. Why optical fibre is more useful tool for the communication process?
17.2. Which is more reliable floppy disk or a hard disk?
17.3. What is the difference between RAM and ROM memories?





Unit 18

ATOMIC AND NUCLEAR PHYSICS

After studying this unit, students will be able to:

- describe the structure of an atom in terms of a nucleus and electrons.
- describe the composition of the nucleus in terms of protons and neutrons.
- explain that number of protons in a nucleus distinguishes one element from the other.
- represent various nuclides by using the symbol of proton number *Z*, nucleon number *A* and the nuclide notation *X*.
- explain that some nuclei are unstable, give out radiation to get rid of excess energy and are said to be radioactive.
- describe that the three types of radiation are α, β & γ.
- state, for radioactive emissions:
  - their nature
  - their relative ionizing effects
  - their relative penetrating abilities
- explain that an element may change into another element when radioactivity occurs.
- represent changes in the composition of the nucleus by symbolic equations when alpha or beta particles are emitted.
- describe that radioactive emissions occur randomly over space and time.
- explain the meaning of hal-life of a radioactive material.
- describe what are radioisotopes. What makes them useful for various applications?
- describe briefly the processes of fission and fusion.
- show an awareness of the existence of background radiation and its sources.
- describe the process of carbon dating to estimate the age of ancient objects.
- describe hazards of radioactive materials.

Science, Technology and Society Connections

The students will be able to:

- describe how radioactive materials are handled, used, stored and disposed of, in a safe way.
- make a list of some applications of radioisotopes in medical, agriculture and industrial fields.
- make estimation of age of ancient objects by the process of carbon dating.

Scientists were always interested to know the smallest particle of matter. Greek Philosopher Democritus in 585 BC postulated that matter is built from small particles called atoms. The atom means indivisible in Greek language. Rutherford in 1911, discovered that atom had a central part called the nucleus. In this unit, we will describe different aspects of atomic and nuclear physics such as radioactivity, half-life, nuclear reactions, fission and fusion.

For your information

The word atom is derived from the Greek word "otomos", meaning "indivisible." At one time, atoms were thought to be the smallest particles of matter. Today we know that atoms are composite systems and contain even smaller particles: protons, neutrons and electrons.

18.1 ATOM AND ATOMIC NUCLEUS

Rutherford discovered that the positive charge in an atom was concentrated in a small region called nucleus. The nucleus contains protons and neutrons which are collectively called nucleons. Atom also contains electrons which revolve in nearly circular orbits about the positively charged nucleus (Fig. 18.1). The simplest atom is that of hydrogen, nucleus of which is a single proton. We describe an element with respect to its nucleus and use the following quantities:

The **atomic number** Z is equal to the number of protons in the nucleus.

The **neutron number** N is equal to the number of neutrons in the nucleus.

The **atomic mass number** A is equal to the number of nucleons (protons + neutrons) in the nucleus i.e., $A=Z+N$.

The mass of neutron is nearly equal to that of proton. But proton is about 1836 times heavier than an electron. So the mass of an atom is nearly equal to the sum of masses of protons and neutrons.

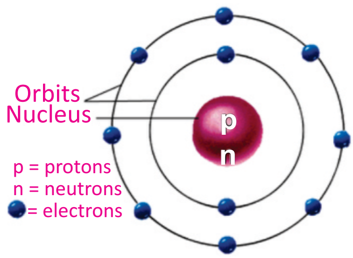


Fig.18.1: The nucleus of an atom consists of protons and neutrons

Generally, an atom is represented by the symbol $^{A}_{Z}X$. For example, nuclide of hydrogen atom having only one proton is $^{1}_{1}H$.

Example 18.1: Find the number of protons and neutrons in the nuclide defined by $^{13}_{6}X$.

Solution: From the symbol, we have

Atomic number Z = number of protons = 6

Atomic mass A = number of protons + number of neutrons = 13
But number of protons are 6, so number of neutrons will be 7.
So the element is an isotope of carbon-6, and is written as $^{13}_{6}C$.

ISOTOPES

Isotopes are atoms of an element which have same number of protons but different number of neutrons in their nuclie. Three isotopes of Hydrogen are shown in Fig.18.2. Protium ($^{1}_{1}H$) contains one proton in the nucleus and one electron that revolves round the nucleus. Deuterium ($^{2}_{1}H$) contains one proton, one neutron and one electron. Tritium ($^{3}_{1}H$) contains one proton, two neutrons and one electron.

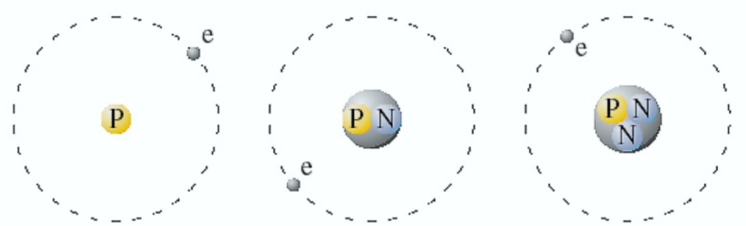
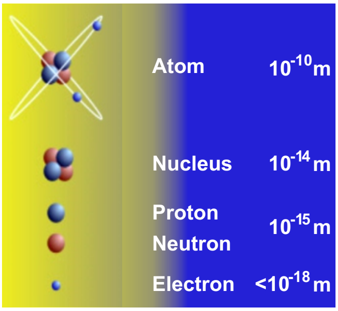


Fig.18.2: Three isotopes of hydrogen Protium ($^{1}_{1}H$), Deutrium ($^{2}_{1}H$) and Tritium ($^{3}_{1}H$) .

For your information



Size of atom and its constituents.

18.2 NATURAL RADIOACTIVITY

In 1896, Becquerel accidentally discovered that uranium salt crystals emit an invisible radiation that can darken a photographic plate. He also observed that the radiation had the ability to ionize a gas. Subsequent experiments by other scientists showed that other substances also emited radiations. The most significant investigations of this type were conducted by Marie Curie and her husband Pierre. They discovered two new elements which emitted radiations. These were named polonium and radium. This process of emission of radiations by some elements was called natural radioactivity by Marie Curie.

Subsequent experiments performed by Henrey Becquerel suggested that radioactivity was the result of the decay or disintegration of unstable nuclei.

The spontaneous emission of radiation by unstable nuclei is called natural radioactivity. And the elements which emit such radiations are called radioactive elements.

Three types of radiation are usually emitted by a radioactive

Do you know?

The positively charged protons in a nucleus have huge electrical forces of repulsion between them. Why do not they fly apart in response to this force? Because there is an attractive force between the nucleons called the strong force. This force acts over only a very short distance. Without this strong nuclear force, there would be no atoms beyond hydrogen.

substance. They are: alpha (α) particles; beta (β) particles; and gamma (γ) rays. These three forms of radiations were studied by using the scheme shown in Fig. 18.3. The radioactive source is placed inside the magnetic field. The radiation emitted from the source splits into three components: α and β-radiations bend in opposite direction in the magnetic field while γ-radiation does not change its direction.

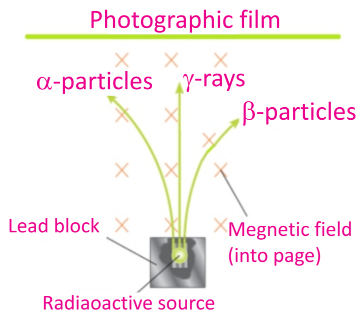


Fig.18.3: Three types of radiations can be distinguished from their path followed in an external magnetic field

18.3 BACKGROUND RADIATIONS

Radiations present in atmosphere due to different radioactive substances are called background radiations (Fig.18.4). Everywhere in rocks, soil, water, and air of our planet are traces of radioactive elements. This natural radiation is called the background radiation. It is as much part of our environment as sunshine and rain. Fortunately, our bodies can tolerate it. Only places where radiation is very high can be injurious to health.

The Earth, and all living things on it also receive radiation from outer space. This radiation is called cosmic radiation which primarily consists of protons, electrons, alpha particles and larger nuclei. The cosmic radiation interacts with atoms in the atmosphere to create a shower of secondary radiation, including X-rays, muons, protons, alpha particles, electrons, and neutrons.

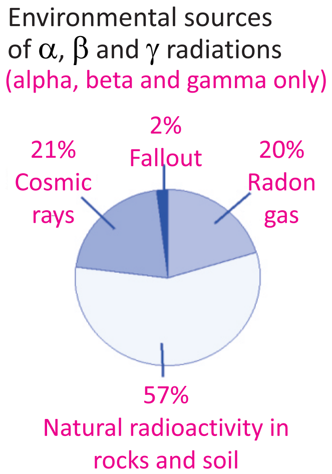


Fig.18.4: The sources of background radiation from the environment

18.4 NUCLEAR TRANSMUTATIONS

We know that during natural radioactivity, an unstable nucleus of radioactive element disintegrates to become more stable.

The spontaneous process in which a parent unstable nuclide changes into a more stable daughter nuclide with the emission of radiations is called nuclear transmutation

Now we represent radioactive decay by means of a nuclear equation in which an unstable parent nuclide *X* changes into a daughter nuclide *Y* with the emission of an alpha particle, beta particle or gamma particle.

1. Alpha (α)-decay

General Equation:

$$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He + \text{Energy}$$

parent nuclide → daughter nuclide + α-particle

Example: $^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He + \text{Energy}$

radium → radon + α-particle

It means in alpha decay, the proton number or atomic number Z of the parent nuclide reduces by 2 and its mass number or nucleon number A decreases by 4.

2. Beta (β)-decay

General Equation:

$$^{A}_{Z}Z \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \text{Energy}$$

parent nuclide → daughter nuclide + β-particle

Example: $^{14}_{6}C \longrightarrow {}^{14}_{6}N + {}^{0}_{-1}e + \text{Energy}$

carbon → nitrogen + β-particle

In beta (β)-decay , the parent nuclide has its proton number Z increased by 1 but its mass number or nucleon number A remains unchanged.

3. Gamma (γ)-decay

General Equation:

$$^{A}_{Z}X^{\star} \longrightarrow {}^{Z}_{6}X + \gamma$$

parent nuclide → daughter nuclide + gamma rays

Example: $^{60}_{27}Co^{\star} \longrightarrow {}^{60}_{27}Co + {}^{0}_{0}\gamma + \text{Energy}$

cobalt → cobalt + γ-rays

Gamma rays are usually emitted alongwith either an alpha or a beta particle.

Nature and Properties of Radiations

Alpha particle is a helium nucleus comprising of two protons and two neutrons with a charge of 2e. An unstable nucleus with large protons and neutrons may decay by emitting alpha radiations. . Beta radiation is a stream of high-energy electrons. An unstable nuclei with excess of neutrons may eject beta radiations. Gamma radiations are fast moving light

For your information

The SI unit for radioactivity is the becquerel, Bq. In SI base units, 1 Bq = 1disintegration per second (dps). This is a very small unit. For example, 1.0 g of radium has an activity of 3.7 3 × 10^{10} Bq. Therefore, the kilobecquerel (kBq) and the megabecquerel (MBq) are commonly used. The activity of 1.0 g of radium is 3.73×10^{4}MBq.

Physics Insight

when alpha and beta particles are slowed down by collisions, they become harmless. in fact, they combine to form neutral helium atoms.

photons. They are electromagnetic radiations of very high frequency (short wavelength) emitted by the unstable excited nuclie.

Ionizing Effect

The phenomenon by which radiations split matter into positive and negative ions is called ionization. All three kinds of radiations i.e., alpha, beta and gamma can ionize the matter. However, alpha particles have the greatest power of ionization as compared to beta particles and gamma rays. It is due to large positive charge and large mass of alpha particles. Beta particles ionize a gas much less than alpha particles. The ionization power of gamma rays is even less than that of beta particles. Ionization of three radiations in a gas is shown in Fig. 18.5.

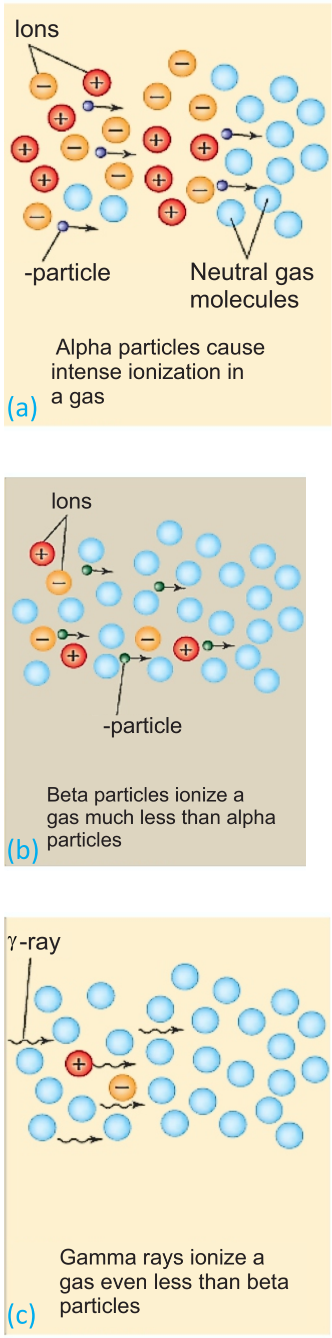


Fig. 18.5: Ionization effect of radiations in a gas

Penetrating Ability

The strength of radiations to penetrate a certain material is called penetrating power. The alpha particle has the shortest range because of its strong interacting or ionizing power. The gamma rays can penetrate a considerable thickness of concrete. It is due to their large speed and neutral nature.

The beta radiation strongly interacts with matter due to its charge and has a short range as compared to gamma radiations. Fig. 18.6 shows the relative penetrating abilities of three kinds of radiations.

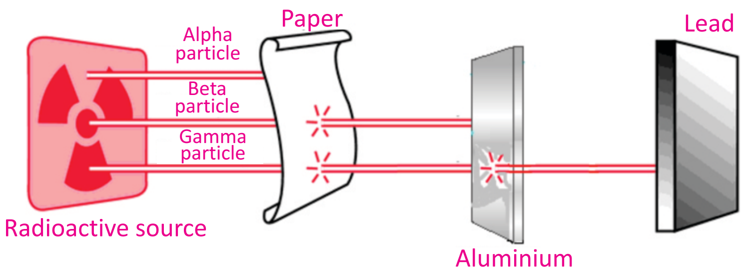


Fig.18.6: Penetrating power of radiations in different materials

Alpha particle has a range of only a few centimetres in air. Beta particles have range of several metres in air. However, gamma rays have a range of several hundreds metres in air.

18.5 HALF-LIFE AND ITS MEASUREMENT

Process of radioactivity is random and the rate of radioactive decay is proportional to the number of unstable nuclei present. In the process, a constant fraction of large number of unstable radioactive nuclei decays in a certain time. So the life time of the unstable nuclei is unlimited and is difficult to measure. We can get the idea about decay rate by the term half-life.

Remember		
Three types of Radiations		
Alpha Particle	**Beta Particle**	**Gamma Ray**
Charge +2	Charge −1	No charge
Least penetration	Moderate penetration	Highest penetration
Transmutes nucleus: $A \rightarrow A - 4$ $Z \rightarrow Z - 2$ $N \rightarrow N - 2$	Transmutes nucleus: $A \rightarrow A$ $Z \rightarrow Z + 1$ $N \rightarrow N - 1$	Changes only energy $A \rightarrow A$ $Z \rightarrow Z$ $N \rightarrow N$

Half-Life

The time during which half of the unstable radioactive nuclei disintegrate is called the half-life of the sample of radioactive element.

Every radioactive element has its own characteristic half-life. For example, radium-226 has a half-life of 1620 years, which means that half of a radium-226 sample will be converted to other elements by the end of 1620 years (Fig.18.7). In the next 1620 years, half of the remaining radium will decay, leaving only one-fourth the original amount of radium, and so on.

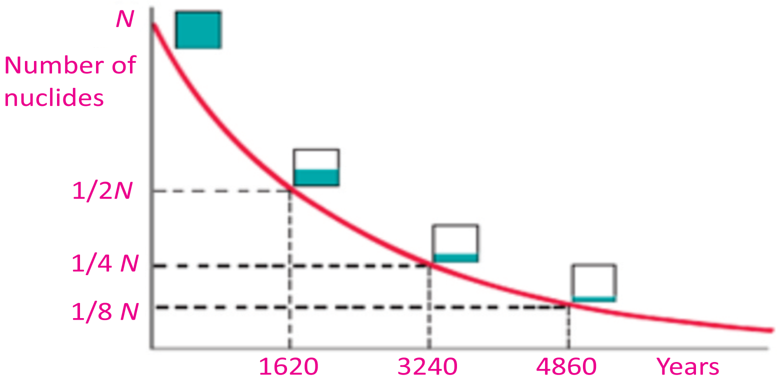


Fig.18.7: Radioactivity of radium

Alpha (α) Particles
Positively charged particles (helium nuclei), ejected at high speed with a range of only a few centimetres in air. They can be stopped by an ordinary sheet of thin aluminium foil.

Beta (β) Particles
Streams of high-energy electrons, ejected at various speeds as high as close to the speed of light. Beta particles may be able to penetrate several millimetres of aluminium.

Gamma (γ) Rays
Electromagnetic radiation of very short wavelenght. Their wavelengths and energies can vary. High-energy gamma rays can penetrate at least 30 cm of lead or 2 km of air.

For your information

i. Nuclear radiation is measured in units of roentgen equivalent man (rem), a unit of equivalent dose.
ii. Patient should be exposed to X-rays with the limit of 0.1 to 1.0 rem.
iii. Safe limit of radiation exposure is 5.0 rem per year.

Physics insight

A half-life is the time a radioactive element takes for half of a given number of nuclei to decay. During a second half-life, half of the remaining nuclei decay, so in two half-lives, three-quarters of the original material has decayed, not all of it.

If the half-life of the radioactive element is $T_{1/2}$, then at the end of this time the number of atoms in the sample will become half i.e., 1/2. After a time $2T_{1/2}$, i.e., after second half-life period, the number of remaining atoms will become $1/2.1/2 = 1/2^2 = 1/4$, after a time 3 $T_{1/2}$, the number of remaining atoms left will be$1/2.1/2.1/2 = 1/2^3 = 1/8$, and at the end of '*t*' half lives number of atoms that remain will be $1/2^t$. It means that if N_o is the original number of atoms in the sample of radioactive element, then after '*t*' half-lives number of atoms left in the sample can be determined by using the relation,

$$\text{Remaining atoms} = \text{Original atoms } 1/2^t$$

$$\text{or} \quad N = N_o \times 1/2^t$$

The process of radioactivity does not depend upon the chemical combinations or reactions. It is also not affected by any change in physical conditions like temperature, pressure, electric or magnetic fields.

Example 18.2: The activity of a sample of a radioactive bismuth decreases to one-eight of its original activity in 15 days. Calculate the half-life of the sample.

Solution: Let $T_{½}$ is the half-life and A_o is the original activity of the sample. After time $T_{½}$ activity will be $A_o/2$. After $2T_{½}$ activity will become$1/2.\ A_o/2 = A_o/4$. While after time $3T_{½}$, i.e., after three half-lives, the activity will drop to $A_o/8$. It means activity drops to one-eighth of original activity in a time of $3T_{½}$.

Therefore, $3T_{½} = 15$. This means half-life $T_{½}$ of the sample will be 5 days.

Example 18.3: A radioactive element has a half-life of 40 minutes. The initial count rate was 1000 per minute. How long will it take for the count rate to drop to (a) 250 per minutes (b) 125 per minutes (c) Plot a graph of the radioactive decay of the element.

Solution: The initial count rate is 1000, therefore,

$$1000 \xrightarrow{40\text{ min.}} 500 \xrightarrow{40\text{ min.}} 250 \xrightarrow{40\text{ min.}} 125$$

(a) As clear from above, it takes 2 half-lives for the count rate

Be careful !

International symbol that indicates an area where radioactive material is being handled or produced.

Radiation Treatment

Gamma radiations destroy both cancerous cells and healthy cells. Therefore, the beam of radiation must be directed only at cancerous cells.

to decrease from 1000 to 250 per min, hence

Time taken = 2 × 40 min. = 80 min.

(b) It takes 3 half-lives for the count rate to decrease from 1000 to 125 per min, hence

Time taken = 3 × 40 min. = 120 min = 2 h

(c) Graph is shown in Fig 18.8.

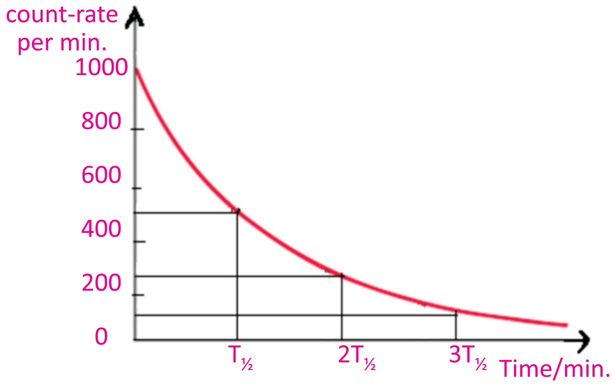


Fig. 18.8: Decay of unstable element

For your information

During brain radiotherapy, patient is carefully positioned in the helmet to ensure that the *gamma* rays converge at the desired point in the brain. A lead apron protects the body from exposure to radiation.

18.6 RADIOISOTOPES AND THEIR USES

Nuclei which do not emit radiations naturally are called stable nuclei. In general, most of the nuclei with atomic number 1 to 82 are stable nuclei. While the elements whose atomic number is greater than 82 are naturally unstable. They emit different types of radiations, all the time, and hence continuously change from one type of element to another.

The stable and non-radioactive elements can also be changed into radioactive elements by bombarding them with protons, neutrons or alpha particles. Such artificially produced radioactive elements are called radioactive isotopes or radioisotopes. Here are some examples of the production of radioisotopes:

1. $^{1}_{0}n + ^{23}_{11}Na \longrightarrow ^{24}_{11}Na +$ gamma (γ)-rays

neutron — stable sodium nuclide — a sodium radioisotope

2. $^{4}_{2}He + ^{27}_{13}Al \longrightarrow ^{30}_{15}P + ^{1}_{0}n$

alpha particle — stable aluminium nuclide — a phosphorous radioisotope

Uses of Radioisotopes

Radioisotopes are frequently used in medicine, industry and agriculture for variety of useful purposes. Following are few applications of radioisotopes in different fields.

1. Tracers

Radioactive tracers are chemical compounds containing some quantity of radioisotope. They can be used to explore the metabolism of chemical reactions inside the human body, animals or plants. Radioisotopes are used as tracers in medicine, industry and agriculture. For example, radio iodine-131 readily accumulates in the thyroid gland and can be used for the monitoring of thyroid functioning. For the diagnosis of brain tumor phosphorous-32 is used. The malignant part of the body absorbs more quantity of isotopes, and this helps in tracing the affected part of the body.

In industry tracers can be used to locate the wear and tear of the moving parts of the machinery. They can be used for the location of leaks in underground pipes. By introducing a suitable radioactive tracer into the pipe, the leak can be conveniently traced from higher activity in the region of crack in the pipe.

In agriculture, radio phosphorous-32 is used as a tracer to find out how well the plants are absorbing the phosphate fertilizer which are crucial to their growth (Fig.18.9).

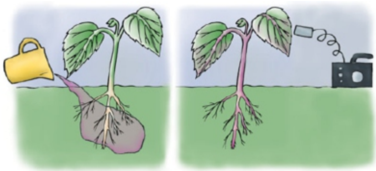


Fig.18.9: To check the action of a fertilizer, researchers combine a small amount of radioactive material with the fertilizer and then apply the combination to a few plants. The amount of radioactive fertilizer taken up by the plants can be easily measured with radiation detectors.

2. Medical Treatment

Radioisotopes are also used in nuclear medicines for curing various diseases. For example, radioactive cobalt-60 is used for curing cancerous tumors and cells. The radiations kill the cells of the malignant tumor in the patient.

3. Carbon Dating

Radioactive carbon-14 is present in small amount in the atmosphere. Live plants use carbon dioxide and therefore become slightly radioactive (Fig. 18.10).

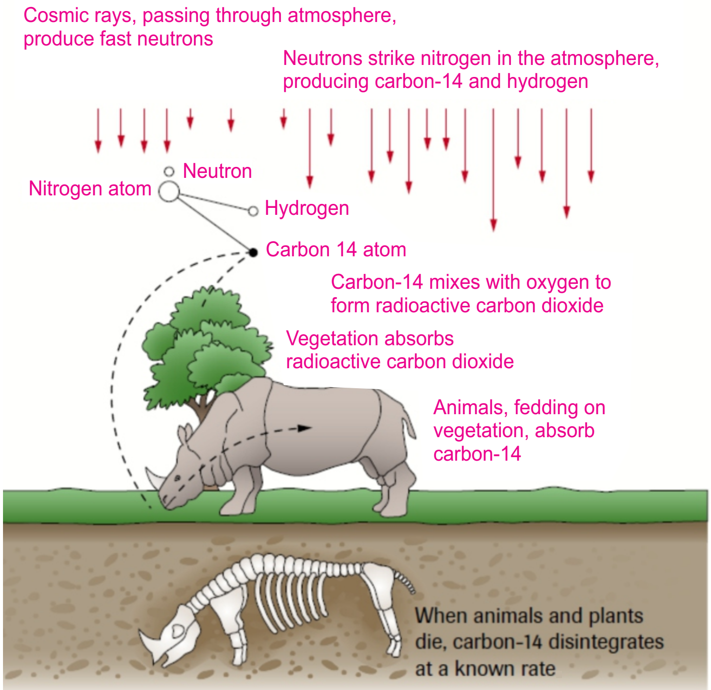


Fig. 18.10: Radiocarbon dating is possible because plants and animals absorb radioactive carbon-14 through their intake of Co_2

When a tree dies, the radio carbon-14 present inside the plant starts decaying. Since the half-life of carbon-14 is 5730 years, the age of a dead tree can be calculated by comparing the activity of carbon-14 in the live and dead tree. The activity of the live tree remains almost constant as the carbon-14 is being replenished while the carbon-14 in the dead tree is no more replenished. Therefore, by measuring the activity in the ancient relic, scientists can estimate its age.

Other radioisotopes are also used to estimate the age of geological specimens. For example, some rocks contain the unstable potassium isotope K-40. This decays to the stable argon nuclide Ar-40 with half-life of 2.4×10^8 years. The age of rock sample can be estimated by comparing the concentrations of K-40 and Ar-40.

Example 18.4: The C-14: C-12 ratio in a fossil bone is found to be $1/4^{th}$ that of the ratio in the bone of a living animal. The half- life of C-14 is 5730 years what is the approximate age of the fossil?

Solution: Since the ratio has been reduced by factor of 4 therefore, two half-lives have passed.

Therefore age of the fossil is given by: 2 x 5730 = 11460 years

18.7 FISSION REACTION

Nuclear fission takes place when a heavy nucleus, such as *U*-235, splits, or fissions, into two smaller nuclei by absorbing a slow moving (low-energy) neutron (Fig. 18.11) as represented by the equation:

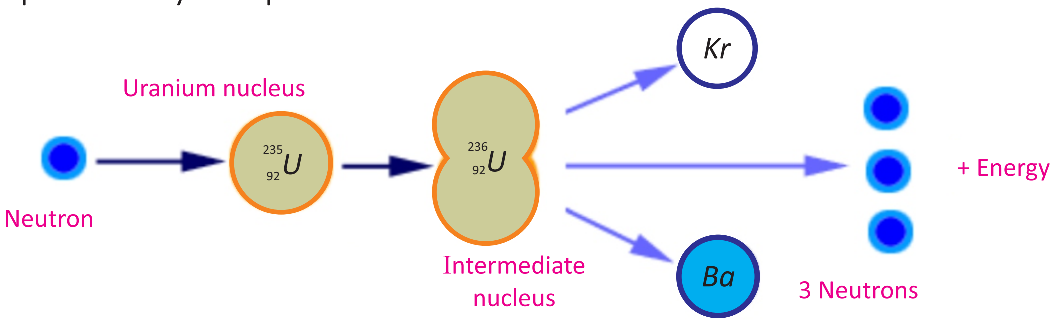


Fig. 18.11: Nuclear fission reaction

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{236}_{92}U^{*} \longrightarrow X + Y + neutron$$

where *U**-236 is an intermediate state that lasts only for a fraction of second before splitting into nuclei *X* and *Y*, called **fission fragments**. Nuclear fission was first observed in 1939 by Otto Hahn and Fritz Strassman. The uranium nucleus was split into two nearly equal fragments after absorbing a slow moving (low-energy) neutron. The process also resulted in the production of typically two or three neutrons per fission event. On the average, 2.47 neutrons are released per event as represented by the expression

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{141}_{56}Ba \longrightarrow {}^{92}_{36}Kr + 3\,{}^{1}_{0}n$$

In nuclear fission, the total mass of the products is less than the original mass of the heavy nucleus. Measurements showed that about 200 MeV of energy is released in each fission event. This is a large amount of energy relative to the amount released in chemical processes. For example, If we burn 1 tonne of coal, then about 3.6×10^{10} J of energy is released. But, during the fission of 1 kg of Uranium-235 about 6.7×10^{11} J of energy is released.

We have seen that neutrons are emitted when *U*-235 undergoes fission. These neutrons can in turn trigger other nuclei to undergo fission with the possibility of a chain reaction (Fig.18.12). Calculations show that if the chain

For your information

Electron volt is also a unit of energy used in atomic and nearly physics:

$1eV = 1.6 \times 10^{-19}$ J

reaction is not controlled, it will proceed too rapidly and possibly results in the sudden release of an enormous amount of energy (an explosion).

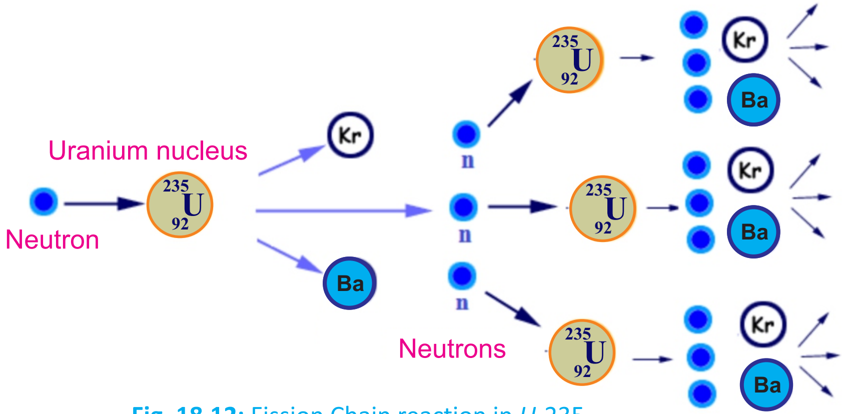


Fig. 18.12: Fission Chain reaction in *U*-235

This fission chain reaction is controlled in nuclear reactors. A nuclear reactor provides energy for useful purposes. In this sort of self sustained reaction, extra neutrons liberated in fission reactions are absorbed using some material to slow down the chain reaction.

Half-lives of Selected Isotopes

Element	Isotope	Half-Life	Radiation Produced
Hydrogen	${}^{1}_{0}H$	12.3 years	β
Carbon	${}^{14}_{6}C$	5730 years	β
Cobalt	${}^{14}_{6}Co$	30 years	β, γ
Lodine	${}^{131}_{53}I$	8.07 days	β, γ
Lead	${}^{212}_{82}Pb$	10.6 hours	β
Polonium	${}^{194}_{84}Po$	0.7 seconds	α
Polonium	${}^{210}_{84}Po$	138 days	α, γ
Uranium	${}^{235}_{92}U$	7.1×10^{8} years	α, γ
Uranium	${}^{238}_{92}U$	4.51×10^{9} years	α, γ
Plutonium	${}^{236}_{94}Pu$	2.85 years	α
Plutonium	${}^{242}_{94}Pu$	3.79×10^{5} years	α, γ

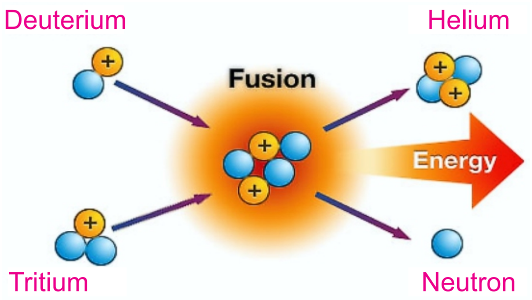
18.8 NUCLEAR FUSION

When two light nuclei combine to form a heavier nucleus, the process is called nuclear fusion.

The mass of the final nucleus is always less than the masses of the original nuclei. According to mass-energy relation this loss of mass converts into energy. If an atom of Deuterium is fused with an atom of Tritium, then a Helium nucleus or alpha particle is formed as given by

$$ {}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n + energy $$

Pictorally fusion reaction is shown in the following figure:



Energy coming from the Sun and stars is supposed to be the result of fusion of hydrogen nuclei into Helium nucleus with release of energy. The temperature at the centre of the Sun is nearly 20 million kelvin which makes the fusion favourable. According to this reaction, four hydrogen nuclei fuse together to form a helium nucleus alongwith 25.7 MeV of energy.

18.9 HAZARDS OF RADIATIONS AND SAFETY MEASURES

Although, radiations are very useful in medicine, agriculture and industry, they can also cause considerable damage if not used with precautions. Radioactive, nuclear materials are now widely used in nuclear power plants, nuclear-powered submarines, intercontinental ballistic missiles etc. Some of the harmful effects on human beings due to large doses or prolonged small doses of radiations are:

1. Radiation burns, mainly due to beta and gamma radiations, which may cause redness and sores on the skin.
2. Sterility (i.e., inability to produce children).

3. Genetic mutations in both human and plants. Some children are born with serious deformities.
4. Leukemia (cancer of the blood cells).
5. Blindness or formation of cataract in the eye.

During the nuclear accident at Chernobyl, Russia, the explosion of the nuclear reactors melted through a few metres thick concrete housing. This caused a massive destruction of local community and also contaminated vegetation and livestock in the large surrounding area. Millions of dollars were lost as the contaminated vegetable and livestock had to be destroyed.

Because we cannot detect radiations directly, we should strictly follow safety precautions, even when the radioactive sources are very weak.

1. The sources should only be handled with tongs and forceps.
2. The user should use rubber gloves and hands should be washed carefully after the experiment.
3. All radioactive sources should be stored in thick lead containers.
4. Never point a radioactive source towards a person.
5. Frequent visits to the radiation sensitive areas should be avoided.

SUMMARY

- There are two parts of an atom. Its central part is called the nucleus which contains neutrons and protons called nucleons. The nucleus is positively charged and electrons revolve around it in nearly circular orbits.
- The number of protons present inside a nucleus is called the charge number or the atomic number and is denoted by the letter Z.
- The sum of neutrons and protons present in a nucleus is called its atomic mass number. It is denoted by the letter A.
- The atoms of same element with same atomic number but different atomic mass number are called isotopes.
- The elements whose atomic number is greater than 82 are unstable. The process of decaying such elements into daughter elements is called natural radioactivity and such elements are called radioactive elements.
- Radioactivity is a random process which does not depend on space and time.

- The time during which the atoms of a radioactive element are reduced to one half is called the half-life of that element.
- Background radiations are caused by some radioactive elements present in rocks, soil and water.
- A process in which nucleus of an unstable heavy element breaks into two nuclei of lighter elements with the emission of radiation is called nuclear transmutation.
- The isotopes which emit radiations are called radioactive isotopes. They are used in medicine, agriculture and industry for a variety of purposes.
- The age of a dead human, animal or tree can be estimated by comparing the activity of carbon-14 in the live and dead tree. The technique is called carbon dating.
- A process in which a heavy nucleus breaks into two nearly equal parts with the release of large energy is called nuclear fission.
- A process in which two light nuclei diffuse to form a heavier nucleus with release of enormous amount of energy is called fusion reaction.

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the following choices:

i. Isotopes are atoms of same element with different

(a)	atomic mass	(b)	atomic number
(c)	number of protons	(d)	number of electrons

ii. One of the isotopes of uranium is $^{238}_{92}U$. The number of neutrons in this isotope is

(a)	92	(b)	146
©	238	(d)	330

iii. Which among the following radiations has more penetrating power?

(a)	a beta particle	(b)	a gamma ray
(c)	an alpha particle	(d)	all have the same penetrating ability

iv. What happens to the atomic number of an element which emits one alpha particle?

(a)	increases by 1	(b)	stays the same
(c)	decreases by 2	(d)	decreases by 1

v. The half-life of a certain isotope is 1 day. What is the quantity of the isotope after 2 days?

(a)	one-half	(b)	one-quarter
(c)	one-eighth	(d)	none of these

vi. When Uranium (92 protons) ejects a beta particle, how many protons will be in the remaining nucleus?

(a)	89 protons	(b)	90 protons
©	91 protons	(d)	93 protons

vii. Release of energy by the Sun is due to

(a) nuclear fission (b) nuclear fusion

(c) burning of gases (d) chemical reaction

viii. When a heavy nucleus splits into two lighter nuclei, the process would

(a) release nuclear energy (b) absorb nuclear energy

(c) release chemical energy (d) absorb chemical energy

ix. The reason carbon-dating works is that

(a) plants and animals are such strong emitters of carbon-14

(b) after a plant or animal dies, it stops taking in fresh carbon-14

(c) there is so much non-radioactive carbon dioxide in the air

(d) when plants or animals die. they absorb fresh carbon -14

REVIEW QUESTIONS

18.1. What is difference between atomic number and atomic mass number? Give a symbolical representation of a nuclide.

18.2. What do you mean by the term radioactivity? Why some elements are radioactive but some are not?

18.3. How can we make radioactive elements artificially? Describe with a suitable example.

18.4. What are the three basic radioactive decay processes and how do they differ from each other?

18.5. Write the alpha decay process for $^{234}_{91}Pa$. Identify the parent and daughter nuclei in this decay.

18.6. Explain whether the atomic number can increase during nuclear decay. Support your answer with an example.

18.7. What do you understand by half-life of a radioactive element?

18.8. Is radioactivity a spontaneous process? Elaborate your answer with a simple experiment.

18.9. What is meant by background radiations? Enlist some sources of background radiations.

18.10. Describe two uses of radioisotopes in medicine, industry or research.

18.11. What are two common radiation hazards? Briefly describe the precautions that are taken against them.

18.12. Complete this nuclear reaction: $^{235}_{92}U \longrightarrow ^{140}_{54}X + ? + 2\ ^{1}_{0}n$. Does this reaction involve fission or fusion? Justify your answer.

18.13. Nuclear fusion reaction is more reliable and sustainable source of energy than nuclear fission chain reaction. Justify this statement with plausible arguments.

18.14. A nitrogen nuclide $^{14}_{7}N$ decays to become an oxygen nuclide by emitting an electron. Show this process with an equation.

18.15. Determine which of these radioactive decay processes are possible:

(a) ${}^{214}_{84}Po \rightarrow {}^{214}_{84}Po + {}^{4}_{2}He$ (b) ${}^{230}_{90}Th \rightarrow {}^{226}_{88}Ra + {}^{4}_{2}He$

(c) ${}^{233}_{91}Pa \rightarrow {}^{233}_{92}U + {}^{0}_{-1}\beta$ (d) ${}^{12}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta$

CONCEPTUAL QUESTIONS

18.1. Is it possible for an element to have different types of atoms? Explain.

18.2. What nuclear reaction would release more energy, the fission reaction or the fusion reaction? Explain.

18.3. Which has more penetrating power, an alpha particle or a gamma ray photon?

18.4. What is the difference between natural and artificial radioactivity?

18.5. How long would you likely have to wait to watch any sample of radioactive atoms completely decay?

18.6. Which type of natural radioactivity leaves the number of protons and the number of neutrons in the nucleus unchanged?

18.7. How much of a 1 g sample of pure radioactive substance would be left undecayed after four half-lives?

18.8. Tritium, ${}^{3}_{1}H$ is radioactive isotope of hydrogen. It decays by emitting an electron. What is the daughter nucleus?

18.9. What information about the structure of the nitrogen atom can be obtained from its nuclide ${}^{14}_{7}N$? In what way atom in ${}^{14}_{7}N$ is different from the atom in ${}^{16}_{7}N$?

NUMERICAL PROBLEMS

18.1. The half-life of ${}^{16}_{7}N$ is 7.3 s. A sample of this nuclide of nitrogen is observed for 29.2 s. Calculate the fraction of the original radioactive isotope remaining after this time.

Ans. (1/16)

18.2. Cobalt-60 is a radioactive element with half-life of 5.25 years. What fraction of the original sample will be left after 26 years? **Ans. (1/32)**

18.3. Carbon-14 has a half-life of 5730 years. How long will it take for the quantity of carbon-14 in a sample to drop to one-eighth of the initial quantity?

Ans. (1.72×10^4 years)

18.4. Technetium-99 m is a radioactive element and is used to diagnose brain, thyroid, liver and kidney diseases. This element has half-life of 6 hours. If there is 200 mg of this technetium present, how much will be left in 36 hours. **Ans.(3.12 mg)**

18.5. Half-life of a radioactive element is 10 minutes. If the initial count rate is 368 counts per minute, find the time for which count rates reaches 23 counts per minute.

Ans. (40 minutes)

18.6. In an experiment to measure the half-life of a radioactive element, the following results were obtained:

Count rate / minute	400	200	100	50	25
Time (in minutes)	0	2	4	6	8

Plot a graph between the count rate and time in minutes. Measure the value for the half-life of the element from the graph. **Ans. (half-life is 2 minutes)**

18.7. A sample of certain radioactive element has a half-life of 1500 years. If it has an activity of 32000 counts per hour at the present time, then plot a graph of the activity of this sample over the period in which it will reduce to 1/16 of its present value.

18.8. Half-life of a radioactive element was found to be 4000 years. The count rates per minute for 8 successive hours were found to be 270, 280, 300, 310, 285, 290, 305, 312. What does the variation in count rates show? Plot a graph between the count rates and time in hours. Why the graph is a straight line rather than an exponential?

Ans. (Variation in count rate shows the random nature of radiactive decay, graph is almost horizontal line rather than exponential curve which is due to long half-life as compared to period of 8 hours)

18.9. Ashes from a campfire deep in a cave show carbon-14 activity of only one-eighth the activity of fresh wood. How long ago was that campfire made?

Ans. (17190 years)

GLOSSARY

AMMETER: An instrument which measures larger current.
AMPERE: If one coulomb of charge passes through any cross section in one second, then current will be equal to one ampere.
AMPLITUDE: The maximum displacement below or above the mean position of a vibrating body.
ANALOGUE ELECTRONICS: The branch of electronics which processes in the form of analogue quantities.
ANALOGUE QUANTITIES: Those quantities which change continuously with time or remain constant.
APERTURE: The line joining the end points of a spherical mirror.
ATOMIC MASS NUMBER: The sum of neutrons and protons present in a nucleus.
BOOLEAN ALGEBRA: The branch of mathematics which deals with the relationships of logic variables.
BOOLEAN VARIABLES: Such things which have only two possible states.
CAPACITANCE: The ability of the capacitor to store charge.
CAPACITOR: A device used to store electric charge.
CAPACITORS IN SERIES: In this combination, the capacitors are connected side by side.
CATHODE-RAY OSCILLOSCOPE: An instrument be used to display the magnitudes of rapidly changing electric current or potential as a function of time.
CATHODE-RAY TUBE: A vacuum tube used to accelerate electrons which emit from the cathode by applying high voltage between cathode and anode.
CENTRE OF CURVATURE: The centre of the hollow sphere of which a spherical mirror is a part.
ATOMIC Number: The number of protons present in a nucleus.
CLADDING: The inner part of the fibre optics.
COMMUNICATION TECHNOLOGY: An electronic based system of information transmission, reception, processing and retrieval.
COMPACT DISC: A molded plastic disc containing digital data that is scanned by a laser beam for the reproduction of recorded sound or other information.
COMPOUND MICROSCOPE: A light microscope used to investigate small objetcs.
COMPRESSIONAL WAVES: The longitudinal waves comprising series of compressions and rarefactions.
COMPUTER: An electronic device used to perform mathematical and logical operations at high speed.
CONCAVE MIRROR: A spherical mirror whose inner curved surface is reflecting.
CONVEX MIRROR: A spherical mirror whose outer curved surface is reflecting.
CONVEX LENS: A lens that causes incident parallel rays to converge at the focal point.
CONCAVE LENS: A Lens which diverges the parallel rays of light from its surface.
COULOMB'S LAW: The force of attraction or repulsion between two charged bodies is

directly proportional to the product of the quantity of charges and inversely proportional to the square of the distance between their centres.

CRESTS AND TROUGHS: In transverse waves, the highest points and the lowest points of the particles of the medium from the mean position.

CYCLE: One complete vibration of a wave.

DATA MANAGING: To collect information for a special purpose and to store it in a computer in a file form.

DATA: Facts and figures that are used by programs to produce useful information.

DIFFRACTION OF WAVES: The bending of waves around obstacles or sharp edges.

DIGITAL ELECTRONICS: The branch of electronics which processes data in the form of digits.

DIGITAL QUANTITIES: The quantities which change in non continuous steps.

ELECTRIC CURRENT: The time rate of flow of electric charge through any cross section.

ELECTRIC POTENTIAL: The amount of work done in bringing a unit positive charge from infinity to a particular point in an electric field.

ELECTRIC POWER: The amount of energy supplied by current in a unit time.

ELECTROMAGNET: The type of magnet which is created when current flows through a coil.

ELECTROMAGNETIC INDUCTION: The production of an electric current across a conductor moving through a magnetic field.

ELECTRON VOLT: The kinetic energy that an electron gains when accelerated between two points with a potential difference of 1 V. $1eV = 1.6 \times 10^{-19} J$

ELECTRONICS: The branch of applied physics which discusses those principles and ways by means of which we control the flow of electrons using different devices.

ELECTROSTATIC INDUCTION: In the presence of a charged body, an insulated conductor having positive charges at one end and negative charges at the other end.

EMF: The total amount of energy supplied by the battery or the cell in moving one coulomb of positive charge from the positive to the negative terminal of the battery.

ENDOSCOPE: A medical instrument used for exploratory, diagnostic, and surgical purposes.

FARSIGHTEDNESS (HYPERMETROPIA): The disability of the eye to form distinct images of nearby objects on its retina.

FAX MACHINE: A mean to send the documents from one place to another through telephone lines.

RIGHT HAND RULE: Grasp a length of wire with your right hand such that your thumb points in the direction of the current. Then fingers of your right hand circling the wire will point in the direction of the magnetic field.

FISSION REACTION: The process of splitting up a heavy nucleus into two smaller nuclei with release of large amount energy.

FLASH DRIVE: A small storage device that can be used to transport files from one computer to another.

FLEMING'S LEFT HAND RULE: Stretch the thumb, forefinger and the middle finger of the left hand are mutually perpendicular to each other. If the forefinger points in the direction of the magnetic field, the middle finger in the direction of the current, then the thumb

would indicate the direction of the force acting on the conductor.
FLOW OF INFORMATION: The transfer of information from one place to another through different electronic and optical equipments.
FOCAL LENGTH: The distance between the principal focus and the pole.
FREE ELECTRONS: Loosely bound electrons in metals which can move from one point to another inside the metals.
FREQUENCY: The number of cycles or vibrations of a vibrating body in one second.
FUSE: A short piece of metal that melts when excessive current passes through it.
FUSION REACTION: A process in which two light nuclei diffuse to form a heavier nucleus with release of enormous amount of energy.
GALVANOMETER: A sensitive electrical instrument which detects current in a circuit.
GENERATOR: A machine that converts mechanical energy into electrical energy.
GOLD LEAF ELECTROSCOPE: A sensitive instrument used to detect electric charge.
GROUNDED: An object connected to a conducting wire or copper pipe buried in the Earth.
HALF-LIFE: The time during which half of the unstable radioactive nuclei disintegrate.
HARDWARE: The parts of a computer that we can see and touch.
LENZ'S LAW: The direction of the induced current is always such that it opposes the cause that produces it.
INFORMATION AND COMMUNICATION TECHNOLOGY (ICT): It is concerned with the scientific methods and means to store and process vast amounts of information instantly.
INFORMATION STORING DEVICES: Devices used to store information for later use and benefits.
INFORMATION TECHNOLOGY: The scientific method used to store information to arrange them for proper use and to communicate them to others.
INTERNET: A computer networks which spreads all across the globe.
ISOTOPES: The elements with same atomic number but different atomic mass number.
KILOWATT-HOUR: The amount of energy obtained by a power of one kilowatt in one hour.
LIGHT PIPE: A bundle of fibre optics bonded together.
LOGIC GATES: The digital circuits which implement the various logic operations.
LONGITUDINAL WAVES: The sound waves in which particles of the medium vibrate along the direction of propagation of the waves.
LOUDNESS: A feature of sound by which a loud and a faint sound can be distinguished.
MAGNIFICATION: The ratio of the image height to the object height.
MECHANICAL WAVES: Those waves which require some medium for their propagation.
MOBILE PHONE: An electronic device with two-way communication. It sends and receives the message in the form of radiowaves.
MUSICAL SOUND: Sound having pleasant effect on our ears.
MUTUAL INDUCTION: The phenomenon of production of induced emf in one coil due to change of current in a neighbouring coil.
NEARSIGHTED (MYOPIA): The defect of eye due to which people cannot see distant objects clearly without the aid of spectacles.

OHM'S LAW: The current passing through a conductor is directly proportional to the potential difference applied across its ends, provided the temperature and physical state of the conductor do not change.
OPTICAL CENTRE: A point on the principal axis at the centre of a lens.
PARALLEL CIRCUIT: A circuit in which voltage remains the same across each resistor.
PERIODIC MOTION: The regular motion of a body which repeats itself in equal intervals of time.
PITCH: The characteristics of sound by which a shrill sound can be distinguished from a grave one.
POLE: The mid-point of the aperture of the spherical mirror.
POWER OF ACCOMMODATION: The ability of the eye to change the focal length of its lens so as to form clear image of an object on its retina.
PRINCIPAL AXIS: The straight line passing through the pole and the centre of curvature of a spherical mirror.
PRINCIPAL FOCUS: A point on the principal axis of mirror/lens where a beam of light parallel to the principal axis converges to or appears to diverge after reflection from the spherical mirror/lens.
PRISM: A transparent triangular piece of glass with at least two polished plane faces inclined towards each other from which light is reflected or refracted.
QUALITY OF SOUND: The characteristics of sound by which two sound waves of same loudness and pitch are distinguished from each other.
RADIOACTIVITY: A phenomenon in which radioactive element emits radioactive rays.
RADIUS OF CURVATURE: The radius of the hollow sphere of which a spherical mirror is a part.
REFLECTION OF LIGHT: When light travelling in a certain medium falls on the surface of another medium, a part of it returns back in the same medium.
REFRACTION: The change of path of waves/light while passing from one medium into another medium due to change in speed.
REFRACTIVE INDEX: The ratio of the speed of light in air to the speed of light in a material:
RESISTANCE: The measure of opposition to the flow of current through a conductor.
RIPPLE TANK: A device used to produce and manipulate water waves.
S.H.M: To and fro oscillatory motion in which acceleration of the body is directly proportional to the displacement of the body from the mean position and is always directed towards the mean position.
SERIES CIRCUIT: A circuit in which current remains the same across each resistor.
SIMPLE MICROSCOPE: A convex lens of short focal length which is used to produce magnified images of small objects.
SOFTWARE: It refers to computer programs and the manuals that support them.
SOLENOID: A coil of wire consisting of many loops.
SOUND: A form of energy that is passed from one point to another in the form of waves.
SPHERICAL MIRROR: A mirror whose polished, reflecting surface is a part of a hollow

sphere of glass or plastic.

THERMIONIC EMISSION: The process of emitting of electrons from hot cathode.

TRANSFORMER: An electrical device which is used to increase or decrease the value of an alternating voltage.

TRANSVERSE WAVES: The mechanical waves in which particles of the medium vibrate about their mean position perpendicular to the direction of propagation of the waves.

TRUTH TABLES: The truth tables are tables which give the values of the inputs and outputs of the basic types of logic gates or combination of such gates.

ULTRASONICS: Sound waves of frequency higher than 20, 000 Hz.

WAVE: A disturbance in a medium which travels from one place to another.

WAVELENGTH: The distance between two consecutive crests or troughs.

WORD PROCESSING: Such a use of computer through which we can write a letter, prepare reports and books, etc.

Electromagnetic

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